Engineering Support Services for:

1200 MW Wind Generation: 20 Year Transmission Development Plan - Exploratory Study

Manitoba Hydro
820 Taylor Ave.
Winnipeg, MB
R3C 0J1 CANADA

Attention:
David Jacobson

Report R1162.01.02

Final Report

Prepared by:
TransGrid Solutions Inc.
200 – 150 Innovation Dr.
Winnipeg, MB R3T 2E1
CANADA

www.transgridsolutions.com

Nov-19, 2010

© TransGrid Solutions Inc, 2010

Disclaimer

This report was prepared by TransGrid Solutions Inc. ("TGS"), whose responsibility is limited to the scope of work as shown herein. TGS disclaims responsibility for the work of others incorporated or referenced herein. This report has been prepared exclusively for Manitoba Hydro and the project identified herein and must not be reused or modified without the prior written authorization of TGS.

Revisions

Project Name:	1200 MW Wind Generation: 20 Year Transmission Development Plan - Exploratory Study
Document Title:	Final Report
Document Type:	Final report
Document No.:	R1162.01.02
Last Action Date:	Nov-19, 2010

Rev. No.	Status	Prepared By	Checked By	Date	Comments
00	IFC	R. Ostash		Oct-8, 2010	Release of draft preliminary report for comments.
01	IFC	R. Ostash		Oct-26, 2010	Release of draft final report based on comments received from Manitoba Hydro.
02	ABC	R. Ostash		Nov-19, 2010	Release of final report based on comments received from Manitoba Hydro.

Legend of Document Status:

Approved by Client	ABC
Draft for Comments	DFC
Issued for Comments	IFC
Issued for Approval	IFA
Issued for Information	IFI
Returned for Correction	RFC
Approval not Required	ANR

© TransGrid Solutions Inc, 2010

This Exploratory Study Report is not intended to eliminate the need for Interconnection Studies.

As per Sections 2.4 and 2.5 of the Manitoba Hydro Open Access Interconnection Tariff:

"**2.4 Exploratory Studies.** Manitoba Hydro, in its sole discretion as a Planning Authority, may conduct an Exploratory Study to provide prospective interconnecting Generators with a rough approximation of the costs associated with the interconnection of a Facility and delivery of energy from a Facility to Manitoba load based on a range of Facility sizes and locations throughout the Province of Manitoba. Exploratory Studies shall be conducted in such a manner to ensure the efficient implementation of Manitoba Hydro's transmission expansion plan in the light of the System's capabilities at the time of the study. Manitoba Hydro shall post on OASIS a notice of intention to perform an Exploratory Study and the scope of the Exploratory Study.

2.5 Exploratory Study Report. Once an Exploratory Study is completed, Manitoba Hydro shall post the Exploratory Study Report on OASIS. An Exploratory Study Report is intended to provide a preliminary, rough approximation of the costs associated with the interconnection of a Facility and delivery of energy from a Facility to Manitoba load, based on Facility size and location, and is not intended to be relied upon by the Generator. Manitoba Hydro makes no representations or warranties with respect to the accuracy, completeness, reliability or suitability of the Exploratory Study Report. Generator assumes any and all risk and responsibility for use and reliance on the Exploratory Study Report. Generator disclaims and waives, any rights or remedies that it might otherwise have against Manitoba Hydro in contract, tort, equity or other legal cause of action for faults, errors, defects, inaccuracies, omissions, suitability or reliability of the Exploratory Study Report."

© TransGrid Solutions Inc, 2010

Table of Contents

Disclaimer i
Revisions i
Table of Contents 3
Executive Summary 5
1. Introduction 20
1.1. Terms of Reference 20
2. Wind Development Scenarios 22
2.1. Wind Build Scenarios for Transmission Analysis 23
2.2. No Wind Scenario - Gas Resource Siting 23
3. Study Models 25
3.1. Manitoba System 25
3.2. Wind Generator Models 26
4. Study Methodology 27
4.1. Contingencies 27
4.2. Criteria 28
4.3. Assumptions 28
5. Development of Transmission Plans 30
5.1. 230kV Transmission Plans 31
5.2. Breakpoints For Network Upgrades 43
5.3. Summary of 230kV Transmission Plan Development 43
5.4. 500kV Transmission Plan 46
6. Transmission Plans for Detailed Study 48
6.1. 600 MW Wind Scenario 48
6.2. 900 MW Wind Scenario 49
6.3. 1200 MW 52
7. Steady State Analysis 57
7.1. 600 MW Wind Scenario 57
7.2. 900 MW Wind Scenario 58
7.3. 1200 MW Wind Scenario 58
7.4. Summary 59
8. Impact to System Losses 60
9. Impact to MH-US Tie Line Power Flows 63
10. Transient Stability Analysis 66
10.1. Overvoltage 66
10.2. Underfrequency 68
10.3. 500kV Transmission Plan: Loss of Wind and 500kV Tie Line 70
10.4. Local Three-Phase Faults 71
10.5. Comparison of Type 3 and Type 4 71
10.6. Summary 72
11. Short Circuit Analysis 73
12. No Wind Scenario 75
12.1. Steady state contingency analysis 75
12.2. Impact to System Losses 75
12.3. Impact to MH-US Tie Line Flows 76
12.4. Short Circuit Analysis 77
12.5. Summary 78
13. Cost Estimates 79
13.1. Unit Cost Estimates 79
13.2. Transmission Plans 79
13.3. Value of Loss Savings 84
13.4. Summary 86
14. Conclusions 87
14.1. Wind Scenarios 87
14.2. No Wind Scenario 89
15. References 90

© TransGrid Solutions Inc, 2010

Appendix 1 – Geographic Locations of Wind Farms 91

© TransGrid Solutions Inc, 2010

Executive Summary

Under a Restrictive Hydro development scenario, the ability of Manitoba Hydro to build new hydro resources to meet either domestic or export requirements would be impaired, resulting in in-service delays for new hydro generation. Manitoba Hydro would have to develop the most economic non-hydro resources until such time it was possible to develop lower cost hydro resources. In a carbon constrained world, a development sequence with some combination of wind generation to provide carbon free energy and natural gas fired thermal generation to provide dispatchable capacity is a logical choice.

There is the potential to connect up to a total of 1200 MW of wind generation in Manitoba to assist in meeting load serving obligations through the year 2030. The wind generation includes the existing 100 MW St. Leon wind plant as well as the 138 MW St. Joseph wind plant.

An Exploratory Study was performed to identify possible transmission solutions for connecting the wind generation to the grid, at an ultimate level of 1200 MW and at scaled back levels of 900 MW and 600 MW. Some of the questions answered by this study include:

- How would the transmission solutions evolve as more wind generation is added?
- At what wind generation level does it become more efficient to have a 500 kV transmission solution instead of a 230 kV transmission solution, or some combination thereof?
- How much do the transmission solutions cost?
- What is the impact to system losses?

There are two wind development scenarios considered in this study: the Pembina Escarpment plan and the Diversified Development plan. The Pembina Escarpment plan involves new wind farms in the geographic region near St. Leon and Stanley. The Diversified Development plan involves new wind farms in the same area as well as wind farms near Killarney and Minnedosa. Appendix 1 shows the geographic locations.

A No Wind scenario was also investigated. This involved a brief look at using thermal generation resources in Manitoba instead of Keeyask or wind generation. In this scenario, the objective was to determine if there are any major network issues with supplying the future load via thermal units at Brandon and Selkirk.

Transmission Plans for Wind Scenarios

Various 230kV transmission plans and one 500kV transmission plan were evaluated to interconnect the 1200 MW wind generation scenario, as well as the scaled back 900 MW and 600 MW wind generation scenarios.

Preliminary steady state analysis evaluated thirteen (13) possible transmission plans with varying wind generation injection points, for both the Pembina Escarpment and Diversified Development plans, at wind generation levels of 600 MW, 900 MW and 1200 MW. Based on the results of this analysis, five suitable 230kV transmission plans were selected for detailed evaluation for both wind development plans, as well as one 500kV transmission plan. They were selected to demonstrate a range of options, from minimal to more substantial transmission additions, in order to compare the transmission plans based on the following factors:

- Cost
- Amount of new transmission to be built
- System losses
- Impacts to the MH-US tie line power flows
- Dynamic system performance
- Impact to system short circuit levels

© TransGrid Solutions Inc, 2010

The selected plans were chosen also because they can be logically staged up from 300 MW to 1200 MW.

The following sections summarize the selected transmission plans in terms of the new facilities and network upgrades required, associated cost estimates and well as the 30-year net present value (NPV) of loss savings.

1) 600 MW Wind Scenario

600 MW 230kV Transmission Plan 1

The 600 MW wind scenario did not require any new network transmission. One transmission plan was studied in detail for each of the wind development plans, as shown in Figure E-1 and described Table E-1.

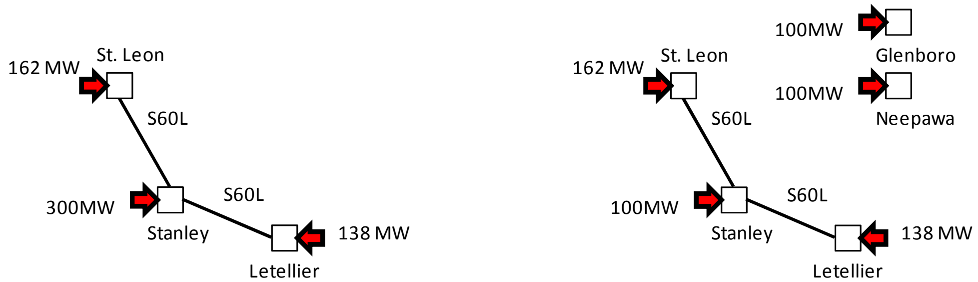


Fig. E-1. Transmission Plan 1 for 600 MW – Pembina Escarpment (left) & Diversified Development (right).

Table E-1. Details of Transmission Plan 1 for 600 MW.

Pembina Escarpment	***Diversified Development***
New Transmission	
None	None
New Breakers/Stations	
• Expand Stanley to 5-breaker ring bus	• Expand Stanley to 5-breaker ring bus • New breaker termination at Glenboro • New breaker termination at Neepawa
Total Length of Direct Connect 230kV Lines	
20 km	120 km
Network Upgrades	
Resag line S53G	None
Cost Estimate	
$29.77 million	$82.73 million
30-year NPV of Loss Savings	
$133.5 - $239.3 million	$149.0 - $267.1 million

The cost estimate for the Pembina Escarpment plan is $52.96 million less than the Diversified Development plan due to the lower length of 230kV direct connect lines required, however it also results in less savings in losses over 30 years, in the range of $15.5 - $27.8 million less.

© TransGrid Solutions Inc, 2010

2) 900 MW Wind Scenario

The 900 MW wind scenarios compared two transmission plans in detail, as shown in Figures E-2(a)-(b) and Tables E-2(a)-(b).

900 MW 230kV Transmission Plan 1

The first plan shown below does not involve any new transmission.

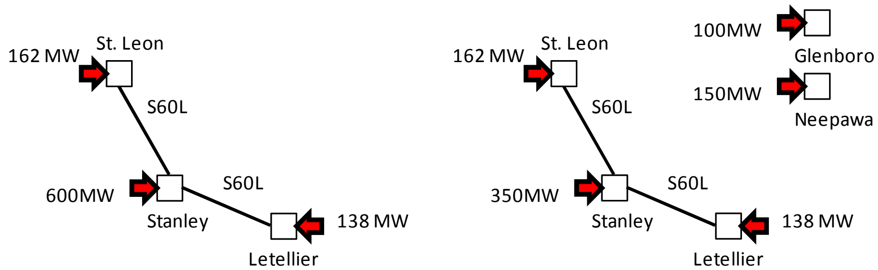


Fig. E-2(a). Transmission Plan 1 for 900 MW – Pembina Escarpment (left) & Diversified Development (right).

Table E-2(a). Details of Transmission Plan 1 for 900 MW.

Pembina Escarpment	***Diversified Development***
New Transmission	
None	None
New Breakers/Stations	
• Expand Stanley to 6-breaker ring bus	• Expand Stanley to 6-breaker ring bus • New breaker termination at Glenboro • New breaker termination at Neepawa
Total Length of Direct Connect 230kV Lines	
71 km	149 km
Network Upgrades	
• Resag line S53G • Replace wavetrap at Stanley	None
Cost Estimate	
$62.78 million	$104.81 million
30-year NPV of Loss Savings	
$184.8 - $331.5 million	$194.4 - $348.5 million

The cost estimate for the Pembina Escarpment plan is $42.03 million less than the Diversified Development plan due to the lower length of 230kV direct connect lines required, however it results in less savings in losses over 30 years, in of $9.6 - $17.0 million less.

© TransGrid Solutions Inc, 2010

900 MW 230kV Transmission Plan 2

The second 900 MW plan shown below involves the addition of a new 230kV wind collector station situated between St. Leon and Stanley, and connected to each via new 230kV transmission.

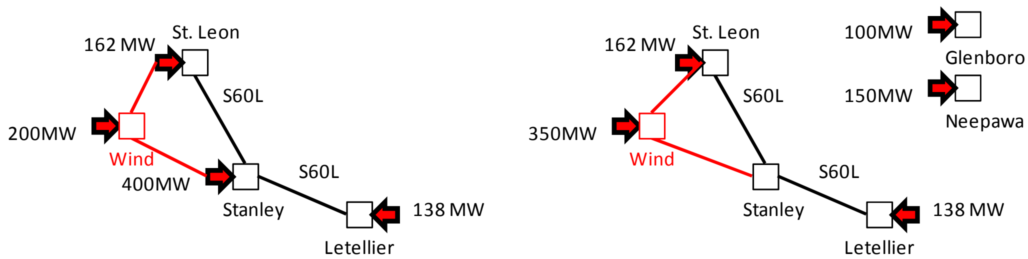


Fig. E-2(b). Transmission Plan 2 for 900 MW – Pembina Escarpment (left) & Diversified Development (right).

Table E-2(b). Details of Transmission Plan 2 for 900 MW.

Pembina Escarpment	***Diversified Development***
New Transmission	
• 230kV Wind Collector – St. Leon (25km) • 230kV Wind Collector – Stanley (40km)	• 230kV Wind Collector – St. Leon (25km) • 230kV Wind Collector – Stanley (40km)
New Breakers/Stations	
• Expand Stanley to 6-breaker ring bus • New 4-breaker wind collector station • New breaker termination at St. Leon	• Expand Stanley to 4-breaker ring bus • New 4-breaker wind collector station • New breaker termination at St. Leon • New breaker termination at Glenboro • New breaker termination at Neepawa
Total Length of Direct Connect 230kV Lines	
88 km	157 km
Network Upgrades	
• Resag line S53G • Replace wavetrap at Stanley	None
Cost Estimate	
$119.11 million	$152.67 million
30-year NPV of Loss Savings	
$193.5 - $347.1 million	$204.4 - $366.6 million

The cost estimate for the Pembina Escarpment plan is $33.56 million less than the Diversified Development plan due to the lower length of 230kV direct connect lines required, however it also results in less loss savings over 30 years, in the range of $10.9 - $19.5 million less.

© TransGrid Solutions Inc, 2010

3) 1200 MW Wind Scenario

The 1200 MW wind scenarios also compared two 230kV transmission plans in detail, as shown in Figures E-3 (a)-(b) and Tables E-3(a)-(b). One 500kV transmission plan was also studied, as shown in Figure E-4 and Table E-4.

1200 MW 230kV Transmission Plan 1

The first plan shown below involves minimal new transmission, with the addition of a new 230kV wind collector station situated between St. Leon and Stanley, connected to each via new 230kV transmission.

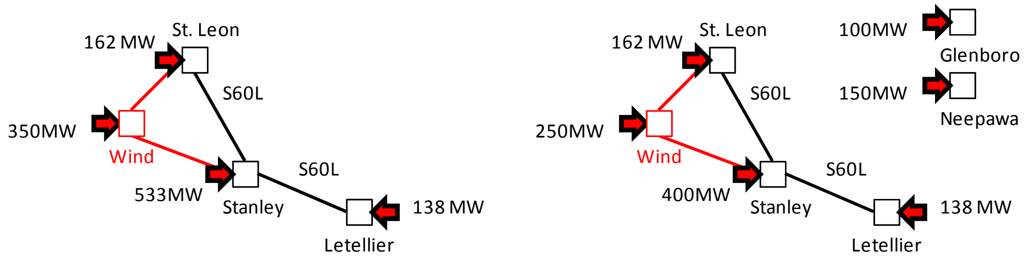


Fig. E-3(a). Transmission Plan 1 for 1200 MW – Pembina Escarpment (left) & Diversified Development (right).

Table E-3(a). Details of Transmission Plan 1 for 1200 MW.

Pembina Escarpment	***Diversified Development***
New Transmission	
• 230kV Wind Collector – St. Leon (25km) • 230kV Wind Collector – Stanley (40km)	• 230kV Wind Collector – St. Leon (25km) • 230kV Wind Collector – Stanley (40km)
New Breakers/Stations	
• Expand Stanley to 6-breaker ring bus • New 6-breaker wind collector station • New breaker termination at St. Leon	• Expand Stanley to 6-breaker ring bus • New 5-breaker wind collector station • New breaker termination at St. Leon • New breaker termination at Glenboro • New breaker termination at Neepawa
Total Length of Direct Connect 230kV Lines	
134 km	208 km
Network Upgrades	
• Reconductor line S53G • Reconductor line S60L Stanley-Letellier • Replace wavetrap at Stanley • Replace wavetrap at Letellier	• Resag line S53G • Replace wavetrap at Stanley
Cost Estimate	
$158.86 million	$190.48 million
30-year NPV of Loss Savings	
$221.5 - $397.3 million	$245.7 - $440.6 million

The cost estimate for the Pembina Escarpment plan is $31.62 million less than the Diversified Development plan due to the lower length of 230kV direct connect lines required, however it also results in less loss savings over 30 years, in the range of $24.2 - $43.3 million.

© TransGrid Solutions Inc, 2010

1200 MW 230kV Transmission Plan 2

The second 1200 MW plan shown below involves significantly more transmission. It expands the first 1200 MW plan to also include a new 230kV line from the wind collector station to Portage and from Stanley to Letellier.

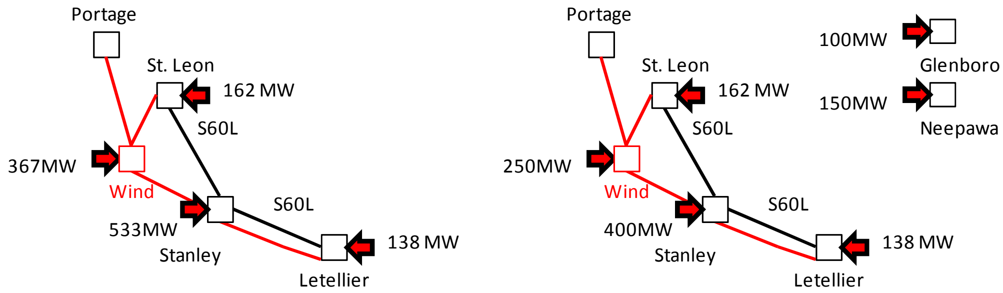


Fig. E-3(b). Transmission Plan 2 for 1200 MW – Pembina Escarpment (left) & Diversified Development (right).

Table E-3(b). Details of Transmission Plan 2 for 1200 MW.

Pembina Escarpment	***Diversified Development***
New Transmission	
• 230kV Wind Collector – St. Leon (25km) • 230kV Wind Collector – Stanley (40km) • 230kV Wind Collector – Portage (70km) • 230kV Stanley – Letellier (65km)	• 230kV Wind Collector – St. Leon (25km) • 230kV Wind Collector – Stanley (40km) • 230kV Wind Collector – Portage (70km) • 230kV Stanley – Letellier (65km)
New Breakers/Stations	
• Expand Stanley to 7-breaker ring bus • New 7-breaker wind collector station • New breaker termination at St. Leon • New breaker termination at Letellier	• Expand Stanley to 7-breaker ring bus • New 6-breaker wind collector station • New breaker termination at St. Leon • New breaker termination at Letellier • New breaker termination at Glenboro • New breaker termination at Neepawa
Total Length of Direct Connect 230kV Lines	
134 km	208 km
Network Upgrades	
• Reconductor line S53G • Replace wavetrap at Stanley	• Resag line S53G
Cost Estimate	
$212.25 million	$249.31 million
30-year NPV of Loss Savings	
$231.6 - $415.3 million	$252.0 - $451.9 million

The cost estimate Pembina Escarpment plan is $37.06 million less than the Diversified Development plan due to the lower length of 230kV direct connect lines required, however it also results in less loss savings over 30 years, in the range of $20.2 - $36.6 million less.

© TransGrid Solutions Inc, 2010

1200 MW 500kV Transmission Plan

One 500kV plan shown below was studied for the 1200 MW scenario. In order to be considered for analysis, a 500kV option should have not much more than half of the length of new transmission than a comparable 230kV solution in order to be economically comparable (due to the higher costs associated with 500kV). This 500kV 1200 MW plan involves a 128km radial 500kV line from a new 230-500kV wind collector station near St. Leon to the Dorsey 500kV station.

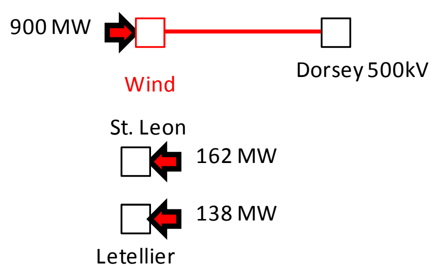


Fig. E-4. Radial 500kV Transmission Plan for 1200 MW.

Table E-4. Details of Radial 500kV Transmission Plan for 1200 MW.

Pembina Escarpment
New Transmission
• 500kV Wind Collector – Dorsey (128km)
New Breakers/Stations/Transformers
• Expand Stanley to 7-breaker ring bus • New 7-breaker 230kV wind collector station • Two new 230-500kV transformers (approx. 1000 MVA each) • Two new 500kV breakers for the transformers
Total Length of Direct Connect 230kV Lines
148 km
Network Upgrades
• None
Cost Estimate
$357.94 million
30-year NPV of Loss Savings
$187.3 - $355.8 million

The cost estimate for the radial 500kV plan is $108.63 - $199.08 million more than the 230kV transmission plans for 1200 MW wind generation. This is due to the higher cost of 500kV transmission as well as the two 230-500 kV transformers that are required.

The radial 500kV plan also results in less loss savings over 30 years compared to the 230kV 1200 MW transmission plans.

© TransGrid Solutions Inc, 2010

Impact to System Losses

As the wind penetration levels in the south increase and the generation in the north decreases, the Manitoba system losses also decrease. The same is true for the no wind scenario, in which thermal units at Brandon and Selkirk are supplying future load. The wind farms and thermal units are located closer to the Manitoba load centre than the northern hydro generators in the base case, hence the reduction in peak losses.

Figure E-5 depicts the range of reduction in losses seen in the wind generation scenarios and the no wind scenario compared to the base case over the summer off-peak to winter peak seasons.

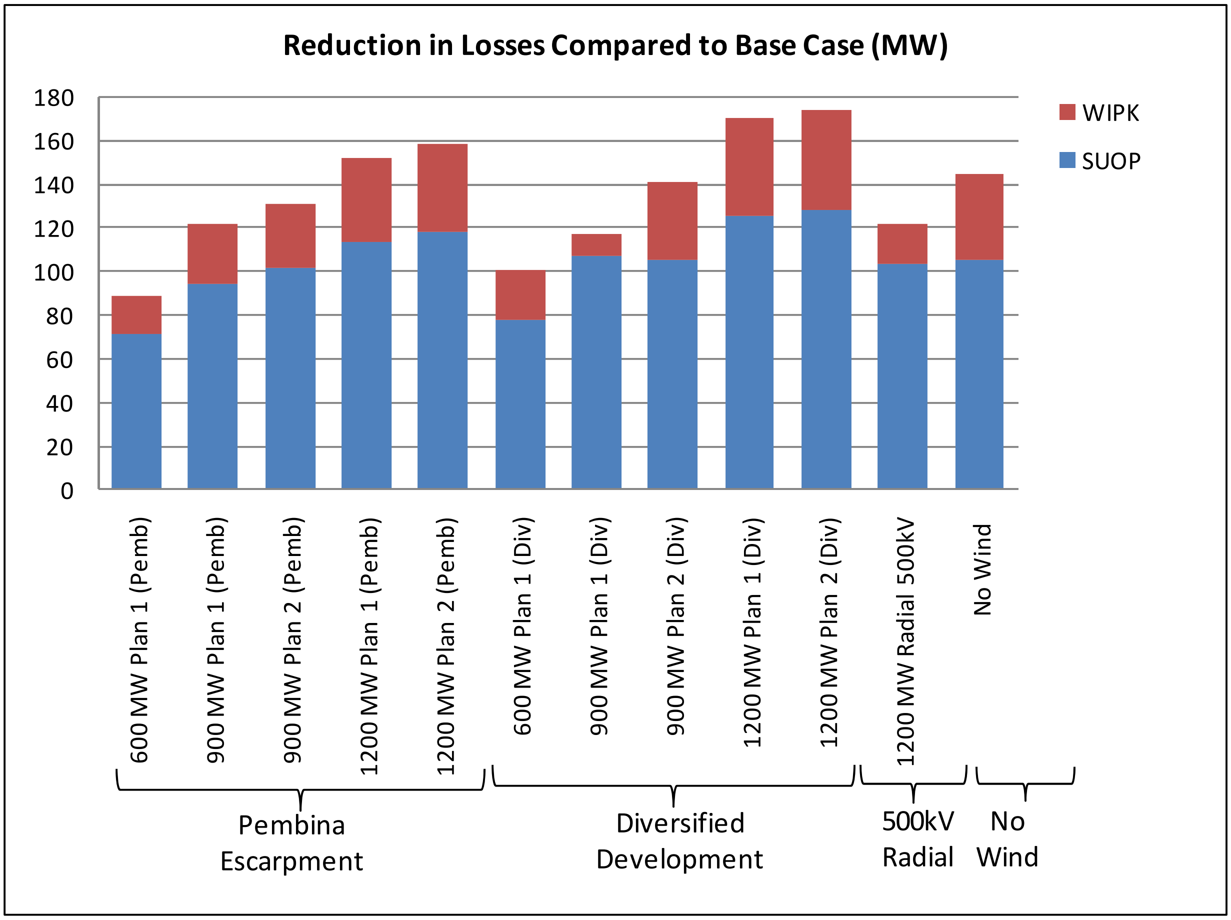


Figure E-5. Reduction in System Losses.

The 230kV Diversified Development plans result in approximately 10-15 MW higher loss reduction (i.e. lower system losses) than the 230kV Pembina Escarpment plans for the same wind MW level.

The 1200 MW radial 500kV transmission plan with the direct feed into Dorsey results in around 20-50 MW lower loss reduction (i.e. higher system losses) compared to the 1200 MW 230kV transmission plans.

System losses are an important factor to consider when designing a transmission plan. During the cost analysis, an estimation of the net present value (NPV) of loss savings over a time span 30 years was calculated, and was included in Tables E-1 through E-5 and depicted in Figure E-8.

© TransGrid Solutions Inc, 2010

Impact MH-US Loop Flow

The 230kV wind scenarios and the no wind scenario reduced or eliminated MH-US loop flow. The highest loop flow occurred in the winter peak case with two 500kV MH-US tie lines. The loop flow and reduction in loop flow for the winter peak cases is depicted in Figure E-6.

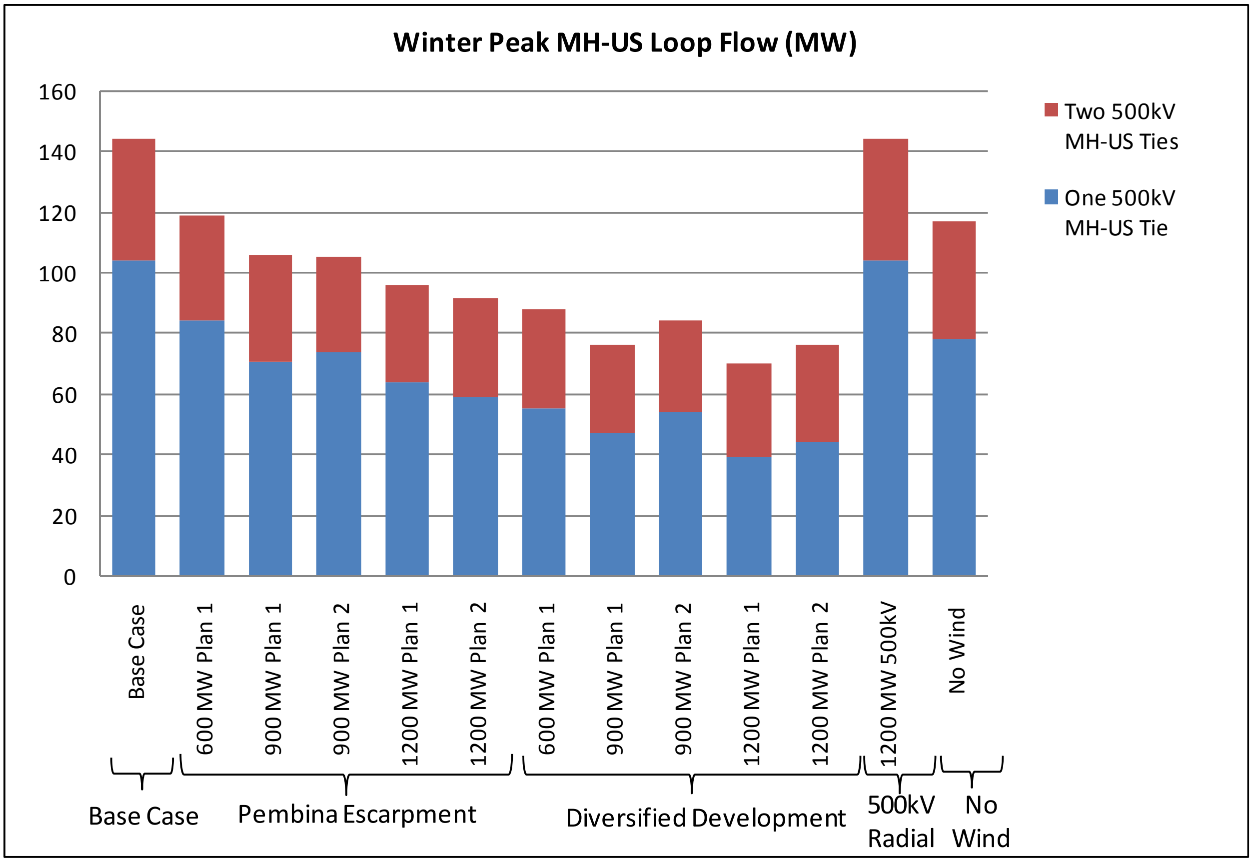


Fig. E-6. Winter Peak MH-US Loop Flows.

Compared to the base case, the 230kV wind scenarios reduce the south flow on the 500kV line(s) and on R50M, and increase the south flow on L20D and especially on G82R. The no wind scenario has similar impacts, with the exception of power flow on L20D – it remains virtually unaffected. The MH-US loop flow in the base case is flowing north on G82R. This means that in the base cases where loop flow exists, such as winter peak and summer peak, the wind generation scenarios and the no wind scenario reduce or eliminate the MH-US loop flow that is flowing north on G82R.

The reduction in MH-US loop flow is not necessarily a good thing, as it results in increased south flow on line L20D in the wind generation scenarios. Loading on line L20D, particularly under low NDEX conditions, is known to be an issue. A previous study [1] found that L20D upgrades were required based on summer export conditions when NDEX is low. The worst contingency was a Category C disturbance in the US at Rugby (loss of Rugby bank and the Rugby-Balta line). This overload will be made worse depending on the status of the Rugby wind farm and the G904 (G82R tap) wind farm, both of which were assumed to trip of for this contingency in that study. This particular contingency was not addressed in this Exploratory Study, nor were the low NDEX conditions.

The approximate percentages of wind plant output flowing south on L20D ranged from 4.7%-9.3% for the case with on 500kV tie line, and from 5.8%-10.4% with two 500kV tie lines.

The power flow cases used in this study were set to intermediate NDEX levels, ranging from 1029 MW to 1492 MW. Further power flow analysis at more stressed NDEX conditions would be required to determine if L20D upgrades would be needed based on the increased L20D south flow associated with the wind

© TransGrid Solutions Inc, 2010

generation scenarios. It is anticipated that with the increases observed in this study that L20D may indeed require upgrading in some of the wind generation scenarios when studied at more stressed NDEX conditions and for a larger list of contingencies.

The radial 500kV transmission plan for the 1200 MW wind scenario has no significant impact on the MH-US tie line power flows. This makes sense as the new wind generation in this transmission plan is feeding directly into Dorsey, while being offset to the HVDC infeed at Dorsey via reduced northern generation at Keeyask and Conawapa. From a power flow perspective, the base case and the wind scenario using the 500kV radial transmission plan are nearly the same.

System Stability

The selected 230kV and 500kV transmission plans were assessed for the interconnection of 600 MW, 900 MW and 1200 MW of wind generation in southwestern Manitoba. The SCRs at the POIs for each transmission plan were 3 or greater. There were no adverse impacts observed to system stability issues in terms of voltages or frequency excursions. In fact, off-loading the HVDC bipoles by replacing hydro generation in the north with wind generation in the south was shown to improve the worst case system underfrequency. Also, the dynamic reactive power support provided by the DFIG wind scenarios improved the system voltage performance with respect to both transient over- and undervoltages. Given the load growth, the base case may eventually require some dynamic reactive support to correct the voltage drop. Type 3 and Type 4 wind generators showed relatively similar performance, although when modeled using a 2-mass rotor representation, the Type 3 wind generators had potential to experience small but poorly damped local torsional oscillations, which took up to five seconds to damp out in the worst cases. These oscillations would require mitigation to meet the 5% damping criteria. Since the oscillations are local to the wind plant, local mitigation in terms of fine tuning wind plant controllers or adding a damping controller may be a solution. It would be recommended to contact GE with regards to these poorly damped oscillations.

Breakdown of Cost Estimates and Loss Savings

Using the following formula,

Annual energy cost = Peak loss savings (MW)*Capacity factor*8760 hours*Energy value ($/MWh)

the net present values (NPV) of the net loss savings were calculated for the wind generation scenarios and the no wind scenario over a period of 30 years at interest rates of 6.0% and 8.5%, at energy values of $50/MWh and $70/MWh. Typical capacity factors for the wind plants could be assumed to be between 30% and 40%, therefore an average value of 35% was used.

Table E-5 provides a breakdown of the cost estimates and the range of 30-year NPV of loss savings associated with the wind scenarios as well as the no wind scenario.

© TransGrid Solutions Inc, 2010

Table E-5. Cost estimates for Transmission Plans and Value of Loss Savings.

Transmission Plan	*Cost Estimates ($ millions)*					*Range of Loss Savings ($ millions)*	
	New Network Transmission	*New Stations/ Breakers*	*New 230kV Wind Lines*	*Network Upgrades*	*Total*	*Min*	*Max*
600 MW – Pembina Escarpment							
Plan 1	0.00	18.94	10.00	0.83	29.78	133.5	239.3
600 MW – Diversified Development							
Plan 1	0.00	22.73	60.00	0.00	82.73	149.0	267.1
900 MW – Pembina Escarpment							
Plan 1	0.00	22.73	35.50	4.55	62.78	184.8	331.5
Plan 2	32.50	41.67	44.00	0.94	119.11	193.5	347.1
900 MW – Diversified Development							
Plan 1	0.00	30.31	74.50	0.00	104.81	194.4	348.5
Plan 2	32.50	41.67	78.50	0.00	152.67	204.4	366.6
1200 MW – Pembina Escarpment							
Plan 1	32.50	49.25	67.00	10.11	158.86	221.5	397.3
Plan 2	80.08	60.62	67.00	4.55	212.25	231.6	415.3
1200 MW - Diversified Development							
Plan 1	32.50	53.04	104.00	0.94	190.48	245.7	440.6
Plan 2	80.08	64.40	104.00	0.83	249.31	252.0	541.9
1200 MW – Pembina Escarpment							
500kV Radial	160.00	123.94	74.00	0.00	357.94	187.3	335.8
No Wind							
None	0.00	0.00	0.00	0.00	0.00	209.6	375.8

Figures E-7 and E-8 depict the cost estimates and the loss savings, respectively.

© TransGrid Solutions Inc, 2010

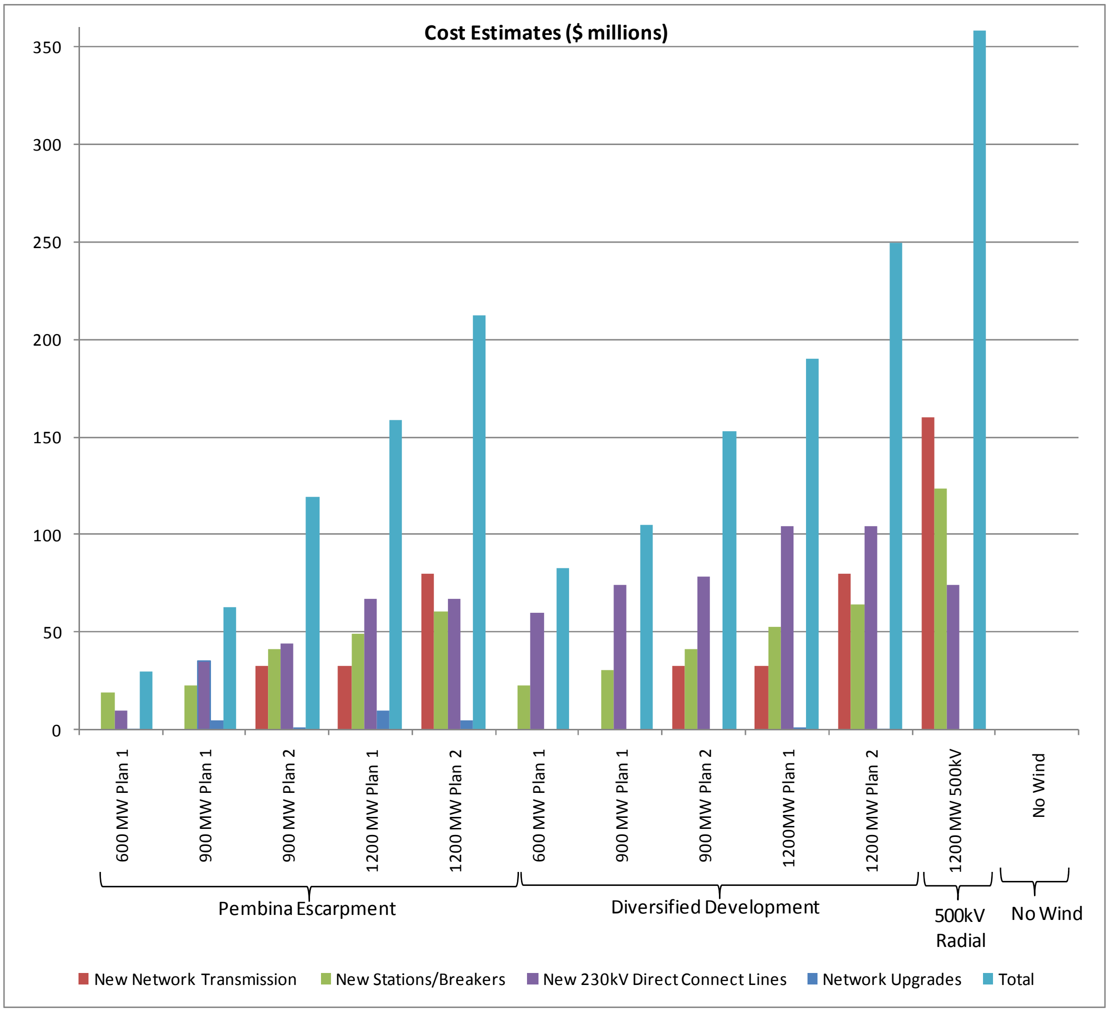


Figure E-7. Breakdown of Cost Estimates.

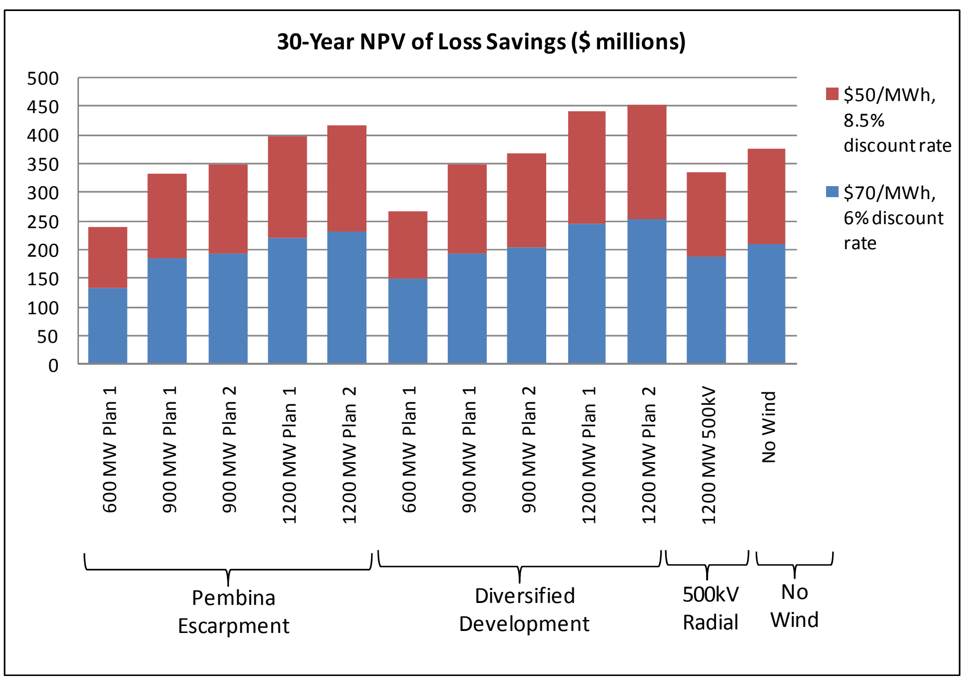


Figure E-8. Range of 30-Year NPV of Loss Savings.

© TransGrid Solutions Inc, 2010

Summary

Wind Scenarios

Of the transmission plans that were studied in detail, there was not a significant difference observed in the dynamic performance of the system when comparing the various plans; the dynamic performance was found to be acceptable for the power flow cases that were investigated. In addition, the SCR at all wind POIs was greater than 3, and the short circuit impacts to the system were minimal. Therefore, the comparison of transmission plans comes down more to cost, impact to system losses and MH-US loop flow, and a plan that could be logically staged.

All wind scenarios were found to reduce the system losses and MH-US loop flow compared to the base case.

500kV vs. 230kV Transmission

Even at the 1200 MW wind generation level, 500kV transmission was not more efficient than 230kV transmission. The 230kV transmission plans have the following benefits when compared to the 500kV transmission plan:

- Lower cost
- Higher value of loss savings over 30 years

There are several additional drawbacks to the 500kV transmission plan.

1) It is less reliable than the meshed 230kV plans. If the 500kV wind-Dorsey line trips, all of the wind generation is lost.

2) There is a risk of subsynchronous control interactions if a Type 3[1] wind turbine is connected radially to a series compensated line. Depending on where the 500 kV wind line would be terminated into the 500kV Dorsey ring bus, it may be next to a series-compensated line, in which case a single contingency could cause the 500kV wind line to be connected radially to the 500kV series-compensated line. If it were more breaker positions away, then it would take more contingencies to cause this situation. The number of contingencies would dictate the risk involved and would determine what type of mitigation to pursue.

3) Another potentially bad situation that could occur is if the 500kV wind line ever tripped at the same time as the 500kV Dorsey-Forbes line when operating a maximum MH-US export. This could potentially result in the loss of ~900 MW of wind power plus the DC reduction due to loss of the 500kV line, for a total power loss of around 2500 MW, which would exceed the contingency reserves in the MISO pool and would be a reliability concern and a likely show stopper. This would be a NERC Category C event as it would take at least one prior outage to get to this

For these reasons, the 500kV radial transmission plan is not recommended.

Pembina Escarpment vs. Diversified Development

For the wind development scenarios, when comparing the Pembina Escarpment plan to the Diversified Development plan, the following conclusions can be made regarding the Diversified Development plan:

Pros:

- Fewer network upgrades are required for the same transmission plan
- More savings in system losses over 30 years
- Less MH-US loop flow
- Less increase in south flow on line L20D

Cons:

- Higher total length of 230kV direct connect transmission lines
- Higher cost estimate (not considering saving in losses)

[1] This is not an issue for Type 4 wind turbines.

© TransGrid Solutions Inc, 2010

Staging of the Transmission Plans with Increased Wind Generation

The transmission plans investigated in this study could be staged as more wind farms are added.

Figure E-9 shows an example of how the Pembina Escarpment plan could evolve from 600 MW to 900 MW to 1200 MW. The network upgrades for each stage are not shown but would be required. A similar staging plan could apply to the Diversified Development plan.

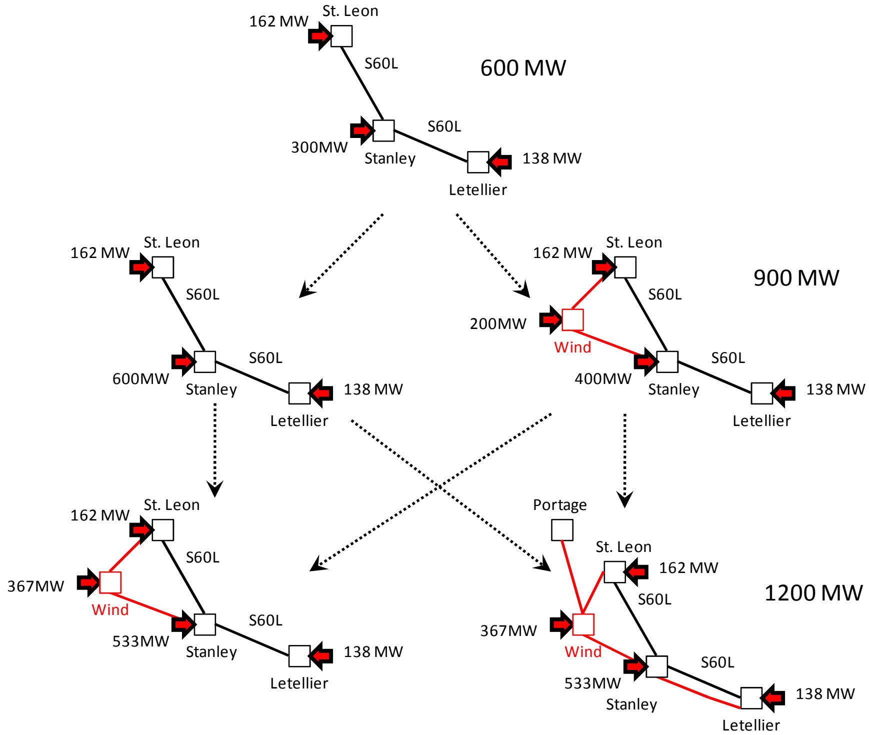


Figure E-9. Example of staged plan to interconnect 600 MW, 900 MW and 1200 MW of wind.

Impact of the 2nd 500kV MH-US Tie Line

The same transmission plans were studied for the cases with one and two 500kV MH-US tie lines. The results of the steady state contingency analysis showed lower network overloads with the second 500kV tie line in service. Despite the fact that the overloads were lower, the overloads were still present and ended up requiring the same mitigation to fix the overloads as the cases with only one 500kV tie line. One exception is the 600 MW Transmission Plan 1, the second 500kV tie line negates the need for resagging line S53G for the Pembina Escarpment plan. Otherwise, all network upgrade requirements were the same whether there were one or two 500kV tie lines. In addition, the total interconnection costs were governed more by the new facilities needed to connect the wind generation, including the direct connect and new 230kV network facilities rather than the cost of network upgrades. Therefore the second 500kV tie line had no significant impact on the total cost of interconnection.

In terms of impacts to system losses, the reduction in losses observed with the wind generation scenarios was similar whether one or two 500kV lines were in service, usually the results were within 10 MW.

In terms of impacts to MH-US tie line power flows, a slightly bigger increase on L20D south flow was observed if the second 500kV tie line was in service. With two 500kV tie lines, L20D south flow increased in the range of 65-90 MW with the wind generation scenarios, as opposed to 52-80 MW with only one 500kV tie line. However, the steady state south flow on L20D was around 60-130 MW lower in the case with the second 500kV tie line, therefore the slightly larger increase in L20D south flow observed with the wind generation if the second 500kV tie line is present may not be the worst case scenario. Further analysis at more stressed NDEX conditions would be required to determine if the increase in south flow on L20D would require L20D upgrades.

© TransGrid Solutions Inc, 2010

No Wind Scenario

Supplying future load via thermal units at Brandon and Selkirk, as well as via hydro generation at Conawapa, was not found to require any new transmission or network upgrades.

With the retirement of Brandon unit 5 (105.9 MW) in 2018, the analysis found that an additional 88.6 MW would be needed at Brandon to maintain the same MHEX levels and serve the same Manitoba load levels as the base cases. This is in addition to the two 140 MW units at Brandon and the two 70 MW units at Selkirk. Although no new transmission or network upgrades are needed, there would be some termination costs associated with this new thermal generation. These termination costs are not considered in this report.

Like the wind scenarios, the no wind scenario reduced system losses as well as MH-US loop flow, but to a lesser degree than the wind scenarios.

The no wind scenario increased the short circuit levels at various southern Manitoba 230kV and 110kV buses, significantly more so than the wind scenarios. Further investigation into the increased fault levels would be required to determine if the levels are acceptable, however it can be stated that all impacted fault levels remained below 40kA, with the exception of the Dorsey 230kV bus which in the worst case increased from 57.8 kA to 61.2 kA.

© TransGrid Solutions Inc, 2010

1. Introduction

There is the potential to connect up to a total of 1200 MW of wind generation in Manitoba to assist in meeting load serving obligations through the year 2030. The wind generation includes the existing 100 MW St. Leon wind plant as well as the 138 MW St. Joseph wind plant.

The goal of this study is to identify possible transmission solutions for connecting the wind generation to the grid. The study looks at an ultimate level of 1200 MW, as well as at levels scaled down in step sizes of approximately 300 MW in order to determine transmission solutions for wind generation interconnection levels ranging from 300 MW to 1200 MW, as follows:

1) 1200 MW
2) 900 MW
3) 600 MW
4) 300 MW (Base level with 138 MW at St. Joseph and 162 MW at St. Leon)

Some of the questions to be answered by this study include:

- How would the transmission solutions evolve as more wind generation is added?
- At what wind generation level does it become more efficient to have a 500 kV transmission solution instead of a 230 kV transmission solution, or some combination thereof?
- How much do the transmission solutions cost?
- What is the impact to system losses?

In order to answer these questions, the main focus of the study is on power flow analysis to check thermal loading, steady state voltages and Manitoba system losses for various transmission solutions for each of the wind generation scenarios. Limited short circuit and transient stability analysis is also performed on the most promising solutions as determined from power flow analysis. The transmission solutions are compared in terms of the total cost estimates, taking into account the cost of losses.

The study investigates two wind development scenarios, one in which the wind farms are located solely in the Pembina Escarpment, and another in which the wind farms locations are somewhat more diversified. A brief look at using thermal generation resources in Manitoba instead of Keeyask or wind generation is also considered. These scenarios are discussed in more detail in Section 2.

1.1. Terms of Reference

The scope of work includes the following:

Task 1 – 1200 MW Wind Generation Scenarios

- Determine one or more feasible transmission solution(s) for each of the two 1200 MW wind generation scenarios: Pembina Escarpment and Diversified Development, including new transmission and upgrades to the existing network such that the system is within criteria.
- Determine whether the solutions involve new 500 kV or 230 kV transmission, or a combination of 500 kV and 230 kV?

Task 2 – Wind Generation Scenarios less than 1200 MW

- Determine one or more feasible transmission solution(s) for 600 MW and 900 MW scaled back versions of the two 1200 MW wind generation scenarios, including new transmission and upgrades to the existing network such that the system is within criteria.

© TransGrid Solutions Inc, 2010

- Do the solutions involve new 500 kV or 230 kV transmission, or a combination of 500 kV and 230 kV? At what MW level does 500 kV become viable?

- Identify intermediate generation levels where significant transmission breakpoint(s) occurs.

- Using knowledge from Task 1, re-define the chosen set of wind generation scenarios if needed.

Task 3 - No Wind Scenario

- Determine if there are any major network issues with supplying the future load via thermal units at Brandon and Selkirk

© TransGrid Solutions Inc, 2010

2. Wind Development Scenarios

Background:

Under a Restrictive Hydro development scenario - the ability of Manitoba Hydro to build new hydro resources to meet either domestic or export requirements would be impaired, resulting in in-service delays for new hydro generation. Manitoba Hydro would have to develop the most economic non-hydro resources until such time it was possible to develop lower cost hydro resources. In a carbon constrained world, a development sequence with some combination of wind generation to provide carbon free energy and natural gas fired thermal generation to provide dispatchable capacity is a logical choice.

As Manitoba Hydro does not have a significant competitive advantage in building and operating natural gas or wind generation, it is anticipated that a wind-gas development sequence would be designed to meet Manitoba domestic load growth, with the preservation of the NSP 375 MW or equivalent capacity sales only in order to preserve transmission access.

Generation Development Sequence Description:

- After the completion of Wuskwatim, no new hydro is developed in Manitoba until 2025
- No future long term export sales beyond the NSP 375 MW sale extension are entered into. In other words - the 125 MW portion of the export sale with NSP and the WPS and MP sales which are contingent upon new hydro are not committed.
- Where the development sequence shows the need for an energy resource - wind energy is selected as a resource
- In order to minimize green house gas emissions, the dependable energy from natural gas fired generation is limited to a 10% annual capacity factor
- Manitoba load growth is assumed to be slightly high- the 2008 base load forecast was used.
- Where the development sequence shows the need for a capacity resource - simple cycle natural gas fired generation is selected as the resource.
- Brandon Unit No 5 is assumed to permanently close mid 2018
- A new Point Du Bois powerhouse is assumed for 2020.
- Conawapa with an in-service date of 2025 and Keeyask with an in-service date of 2039.

Wind Resource Development:

- In determining the quantity of wind required in this sequence, a wind farm average capacity factor of 40% was assumed for the first 1000 MW of wind. Beyond that quantity, the average capacity factor was assumed to drop by 1% for each additional 200 MW block of wind. Dependable energy from wind was assumed to be 85% of the average annual wind farm generation.
- The quantity and timing of wind and natural gas generation to meet the assumptions of the Delayed Hydro Development Sequence is as follows:

	In Service Date	**MW Wind**
St. Leon (existing)	2005	100
St. Joseph (committed)	2011	138
St. Leon (in fill)	2012	62
New Wind	2013	100
New Wind	2019	350 (replaces Brandon 5 energy)
New Wind	2020	100
New Wind	2022	200
New Wind	2024	150
Total Wind		**1200 MW**

Thermal	**In Service Date**	**MW**
LME 6000 CT	2022	86
LME 6000 CT	2024	43
Total Thermal		**129 MW**

© TransGrid Solutions Inc, 2010
TGS TRANSGRID SOLUTIONS

Wind Resource Siting

Beyond the specified locations for St. Leon and St. Joseph, wind development could occur in any of the better quality wind resource locations in southern Manitoba. Practically, the best wind resource in southern Manitoba is in the Pembina escarpment area. The development of large amounts (up to a total of 1000 MW) of wind in the Pembina Escarpment region is possible. These options can be summarized as follows:

Block Name	Description and Location	Size (MW)
A	St. Leon - Existing - 2005 ISD	100
B	St. Joseph (6 km west of Letellier)- 2011 ISD	138
C	St. Leon - in fill - 2012 ISD	62
D	Pembina #3 Notre Dame de Lourdes - post 2012 ISD	117
E	Pembina #2 SE of Darlingford - post 2012 ISD	133
F	Pembina #4 South of Thornhill - post 2012 ISD	100
G	Pembina #5 North of Darlingford - post 2012 ISD	100
H	Pembina #7 NE of Manitou - post 2012 ISD	200
I	Pembina #6 Brown - post 2012 ISD	200
J	Minnedosa - north of Minnedosa - post 2012 ISD	150
K	Killarney - post 2012 ISD	100
L	Dry River - post 2012 ISD	100
M	Purves - east of Purves - post 2012 ISD	100

For planning purposes - blocks A through C should be viewed as common to each scenario. The wind regime for blocks D through M is comparable, so from a resource planning perspective there is no strong order of preference in the selection of these blocks on the planning horizon. The selection of the particular sequence from within Blocks D-M can be optimized to minimize transmission costs, subject to meeting the in-service dates for new wind as specified under the Wind Resource Development section.

2.1. Wind Build Scenarios for Transmission Analysis

Blocks A-C are common to each development sequence.

Wind Build Sequence No 1 - Pembina Escarpment Development
Block G 2013 (100 MW)
Block D,E,F for 2019 (350 MW)
Block H for 2020 (100 MW)
Block I for 2022 (200 MW)
Block L, M for 2024 (150 MW)

Wind Build Sequence No 2 - Diversified Development
Block G 2013 (100 MW)
Block D,E,J for 2019 (350 MW)
Block K for 2020 (100 MW)
Block I for 2022 (200 MW)
Block F (100 MW for 2024), plus 50 MW at either L or M in 2024

2.2. No Wind Scenario - Gas Resource Siting

Given the retirement of Brandon Unit No 5, and the existing gas and power infrastructure at this site - any new thermal capacity is assumed to be located at the existing Brandon G.S.. For the purposes of the transmission study, the gas resources are assumed off line unless required to maximize exports at summer off peak loads. An analysis will be conducted assuming all wind generation is off line in the winter peak and summer off peak cases. Keeyask will be assumed to be offline and the additional future load will be served by Conawapa and thermal generation at Brandon and Selkirk.

© TransGrid Solutions Inc, 2010

With the retirement of Brandon unit 5 (105.9 MW) in 2018, the analysis found that an additional 88.6 MW would be needed at Brandon to maintain the same MHEX levels and serve the same Manitoba load levels as the base cases. This is in addition to the two 140 MW units at Brandon and the two 70 MW units at Selkirk.

© TransGrid Solutions Inc, 2010

3. Study Models

3.1. Manitoba System

The study is performed using several year 2030 power flow cases at various load levels; summer off-peak, summer peak and winter peak. Summer peak is used for the steady state contingency analysis, while summer off-peak and winter peak are used for the transient stability analysis.

The following four base power flow cases are used in the transient stability study:

- Year 2030 winter peak (worst case for transient under-frequencies) with a new MH-US 500 kV tie line and Dorsey-Riel 500 kV connection.
- Year 2030 winter peak (worst case for transient under-frequencies) without a new MH-US 500 kV tie line.
- Year 2030 summer off-peak case with new MH-US 500 kV tie line and Dorsey-Riel 500 kV connection at a maximum exports (3275 MW)
- Year 2030 summer off-peak case without a new MH-US 500 kV tie line at a maximum export level (2175 MW)

The year 2030 winter peak load was modeled at 5774 MW and the summer off-peak load was modeled at 3944 MW. A summer peak case was created for use in steady state contingency analysis by scaling up the Manitoba load (excluding industrial load) to 4907 MW.

Figure 3-1 depicts a high level diagram of the southern terminals of Bipoles 1, 2 and 3 as well as the MH-US tie lines. The blue lines in the diagram apply to the power flow cases with the new 500 kV line.

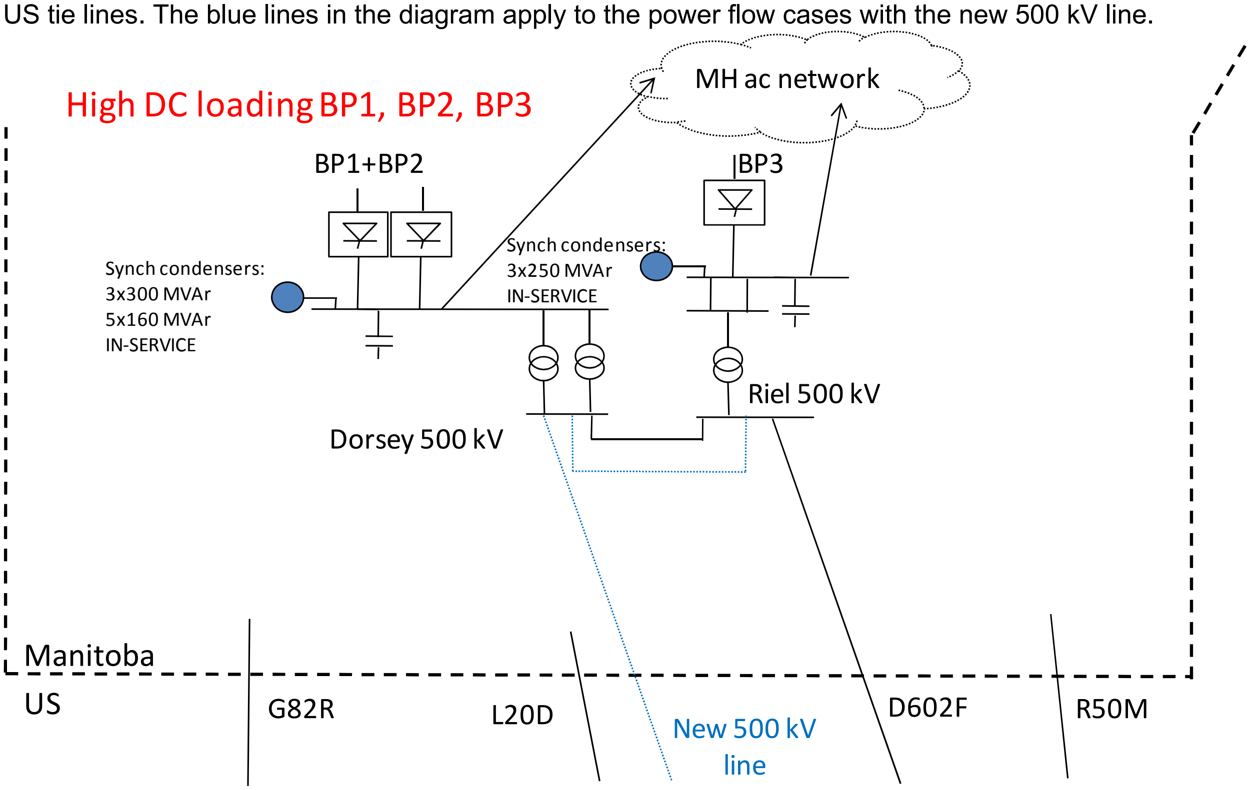


Figure 3-1. DC and MH-US tie line configuration. Blue lines apply to power flow cases with new 500 kV line.

Table 3-1 summarizes the base case power flows.

© TransGrid Solutions Inc, 2010

Table 3-1. Base power flow cases.

Case	*MH DC Loading (MW)*			*MHEX (MW)*	*Manitoba Generation*					*MH-US Tie Lines (MW)*				
	BP1	*BP2*	*BP3*		*WPG River*	*Grand Rapids*	*Bran-don*	*Dorsey MVAR Cushion*	*Riel MVAR Cushion*	*D602F*	*L20D*	*R50M*	*G82R*	*New 500*
SUOP 1x500	1414	1526	1522	2175	653	430	0	931.5	492.6	1567.7	361.2	190.9	54.9	-
SUOP 2x500	1612	1740	1734	3281	653	480	0	842.9	662.1	1373.2	298.5	170.7	31.8	1406.3
WIPK 1x500	1636	1763	1760	1042	653	480	0	889.5	339.9	755.3	224.0	158.4	-97.2	-
WIPK 2x500	1636	1764	1760	1053	653	480	0	829.3	626.7	548.4	155.6	137.2	-137.6	345.4

3.2. Wind Generator Models

The PSSE wind modeling package for GE 1.5/3.6/2.5 MW wind turbines was used to model the various wind farms in this study.

The 1.5 MW and 3.6 MW turbines are the Type 3 wind generations, or the doubly-fed induction generators (DFIG). The majority of the study was performed using Type 3 wind turbines.

The 2.5 MW turbines are the Type 4 wind generators, or the full converter type. A brief sensitivity analysis comparing Type 3 and Type 4 wind farms was investigated in the stability analysis.

Please refer to the PSSE model manuals [2,3] for further detailed information on the GE wind turbine models.

© TransGrid Solutions Inc, 2010

4. Study Methodology

PSSE is used to perform a steady state, short circuit and transient stability study in which the base case and the wind scenarios are evaluated. Various transmission plans are developed to interconnect the wind generation into the grid. The steady state and dynamic performance of the interconnected AC system is compared between the base case and each of the wind scenarios, as well as the peak system losses and MH-US loop flow. Cost estimates are developed for the preferable transmission solutions.

Sensitivity analysis is performed to test the cases with and without the new 500 kV MH-US tie line.

For each of the Wind Generation Scenarios and the No Wind Scenario defined in Section 2, the following steps are taken:

- Based on the geographic locations of the wind farms to be studied, determine appropriate injection points into the grid.
- Add new transmission as necessary to integrate the new wind generation and get the power flow cases to a reasonable system intact starting point.
- Based on the power transfer limit analysis, choose a number of transmission plans to consider for more detailed study. Create the power flow cases to be studied by modifying the base power flow cases to represent the wind generation scenarios and the no wind scenario:
  - For the wind generation scenarios, displace the wind generation with generation at Conawapa and Keeyask, with associated proportional loading adjustments on the three HVDC bipoles.

  For the no wind scenario, Keeyask is assumed to be off-line, with future load being served by Conawapa and thermal generation at Brandon and Selkirk.
- Perform steady state contingency analysis (PSSE activity ACCC) on all power flow cases.
- Modify the new transmission as necessary and find mitigation measures to upgrade the existing network such that all thermal loading is below 100% and steady state voltages remain within acceptable limits.
- Determine one or more feasible transmission solutions for each wind generation scenario.
- Find the peak losses of the system with the new wind generation and transmission solutions. Calculate the cost of the savings/increase in losses compared to the base case, and compared to each other.
- Perform a brief short circuit and stability check on a few of the most preferable solutions. A few key disturbances will be defined for each transmission solution.
- Calculate the cost estimates for the transmission solutions. Compare the costs estimates of the various transmission solutions. Cost estimates will be calculated for each transmission scenario for the direct connect costs, new network transmission costs and the costs for any additional network upgrades identified. The total cost estimates for each transmission scenario will then be compared, taking into consideration the cost of losses.

4.1. Contingencies

For steady state contingency analysis:

- All NERC Category B and C contingencies in Manitoba at voltage levels 115 kV and above. Includes any new transmission added to the model to accommodate the new wind generation.

For transient stability analysis, key disturbances include:

© TransGrid Solutions Inc, 2010

- To test the performance of the wind generators and their associated new transmission plans, and to check for unacceptable voltage performance or oscillations:
  - Three-phase normal-clearing AC faults on nearby 230kV lines and on 230kV outlet lines of any new 230kV wind collector stations.

- To test for system underfrequency:
  - Three phase normal-clearing AC fault at the rectifier buses and Long Spruce bus. The Radisson bus fault will include loss of a 100 MVAr filter and a fault at the Henday bus will include loss of a 200 MVAr filter.

- To test for system overvoltage:
  - Double bipole block, leaving all filters connected

4.2. Criteria

The performance of the system with the wind generation scenarios implemented is compared to that of the base case. Observations are made to compare performance between the base case and the wind scenarios, and to determine the requirements necessary for the wind scenarios to meet the performance criteria outlined in the Transmission System Interconnection Requirements (TSIR) document [4]. Key criteria for this study include:

Steady state:

- Steady state voltages during contingencies must remain between 0.9 pu and 1.1 pu.

- Thermal loading should be at or below 100% of the thermal rating.

Transient:

- Transient underfrequencies should remain above 59.3 Hz.

- Transient undervoltages should remain above 0.7 pu.

- Transient overvoltage should remain below 1.3 pu for 200 ms for credible contingencies.

- Oscillations should have a damping ratio of 5% or greater.

4.3. Assumptions

The following assumptions are applicable to the study:

- The wind farms are assumed to use doubly fed induction generators.

- The per unit cost estimates for new facilities and for upgrading existing facilities as well as the $/MWh values for losses were provided by Manitoba Hydro for use in this study.

- The new wind generation added will displace generation at Keeyask and Conawapa in order to determine transmission requirements between Winnipeg and the wind plant site(s). The generation adjustments will also have associated proportional loading adjustments on the three bipoles.

- Bipole 3 is constructed with a 2000 MW rating.

- One 150 MVAr synchronous condenser is out of service at Dorsey and one 250 MVAr synchronous condenser is out of service at Riel. The base case system has a reactive power reserve of 300 MVAr at Dorsey (therefore can withstand loss of largest synchronous condenser at

© TransGrid Solutions Inc, 2010

Dorsey without invoking SUVC at Dorsey) and a 250 MVAr reserve at Riel (can withstand loss of largest Riel synchronous condenser without invoking SUVC at Riel).

© TransGrid Solutions Inc, 2010

5. Development of Transmission Plans

The Pembina Escarpment wind scenario involves the addition of 900 MW of new wind farms in the geographic region near St. Leon and Stanley. The Diversified Development wind scenario involves the addition of 650 MW of new wind farms also near St. Leon and Stanley, as well as a new 100 MW wind farm near Killarney and a 150MW wind farm near Minnesoda.

For both scenarios, the remaining 300 MW (of the total 1200 MW) is made up of a new 62 MW wind generation addition to the existing 100 MW St. Leon wind farm and the 138 MW St. Joseph wind farm. The approximate geographic locations of the wind farms are shown in Appendix 1 for the Pembina Escarpment and Diversified Development scenarios.

Various 230kV transmission plans were evaluated to interconnect the 1200 MW wind generation scenario, as well as the scaled back 900 MW and 600 MW wind generation scenarios. The potential for a 500 kV transmission plan was assessed following the evaluation of the 230kV transmission plans to see if there were any 500kV transmission plans that could be economically and technically comparable to the 230kV plans.

Power transfer limit analysis (PSSE activity TLTG) was first used to assess various transmission options and interconnection points. This type of analysis provides the wind generation breakpoints at which thermal overloads begin to occur. It is a quick method to study many transmission options in order to narrow down a set of options for more detailed study. Wind generation interconnection points were chosen, and the new wind generation starting from 0 MW up to the maximum amount being considered for each location is injected into these points (and scheduled to Dorsey). TLTG then performs contingency analysis and the generation breakpoints at which thermal loading violations occur are recorded. This analysis assumes there are sufficient reactive power reserves to maintain the system voltages.

Once the set of transmission options was narrowed down based on the results of the power transfer limit analysis, further steady state contingency analysis was performed using PSSE activity ACCC to confirm the results of the power transfer limit analysis. Then the preferred plans were assessed to observe the impacts to system losses, MH-US tie line flows, transient stability performance of the system and short circuit levels in Manitoba.

For the new wind farms near St. Leon and Stanley, depending on the amount of wind generation being considered (600 MW, 900 MW or 1200 MW) it was assumed that one or two 230kV wind collector stations would be used to gather the wind generation and tie into the existing network via new 230kV transmission. The existing Stanley station was assumed to be a possibility for expansion to become one of these wind collector stations. It was also assumed due to physical space limitations that only one new termination into the existing St. Leon 230kV station would be considered.

For the Diversified Development scenario, based on knowledge from a previous wind interconnection study performed near Minnedosa [5], the 150 MW wind farm location near Minnedosa is assumed to connect into the Neepawa 230kV station. Using the 110kV Minnedosa station as the point of interconnection (POI) would require 110kV line MR11 to be rebuilt as well as other major 110kV system upgrades in the area, including installation of a breaker failure protection scheme.

Also for the Diversified Development scenario, the wind farm near Killarney is assumed to connect into the Glenboro 230kV station, despite the fact that tapping MH-US tie line G82R would be the nearest option. G82R is governed by a coordinating agreement between the three owners. Any changes to this line would require a consensus before any construction could begin. There would also be changes required to the out-of-step protection and possibly the DC reduction scheme. This may involve significantly more studies to confirm that the original purpose for constructing G82R could still be met (i.e. transfer capability). As an International Power Line, there would also be the process of going through the NEB for approvals before any construction could begin. In addition, there is also a wind farm at Rugby as well as the G904 wind farm which already taps G82R [6]. A previous Interconnection Facilities Study was performed in 2006 to tap line G82R with a wind farm in a similar vicinity to Killarney [7]. This study

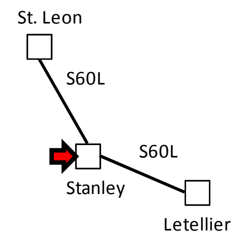
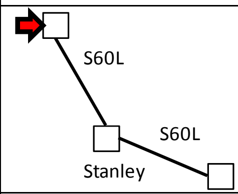
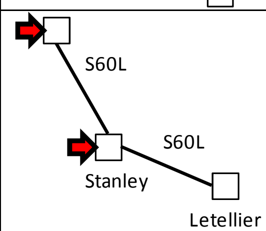
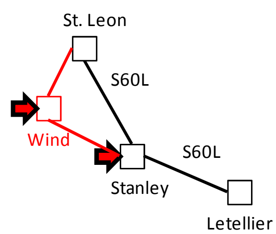
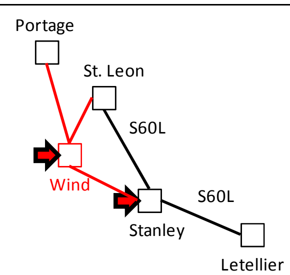
© TransGrid Solutions Inc, 2010

performed sensitivity analysis to the Rugby wind farm, but did not consider the G904 wind farm. This study found thermal loading issues on 230kV line G37C and G82R, both which required upgrades. Due to these complexities, it is simpler to use a POI at an existing Manitoba station.

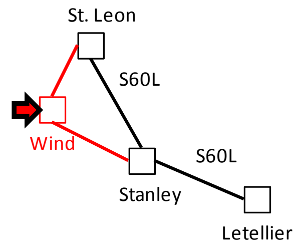
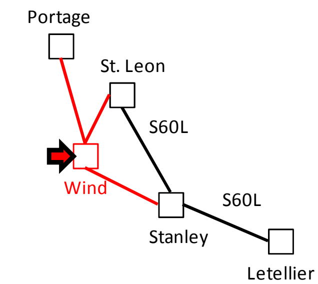
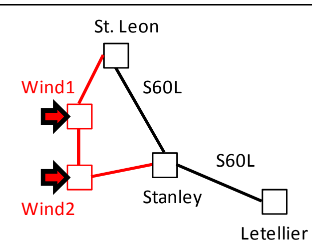
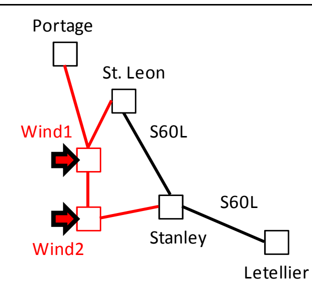
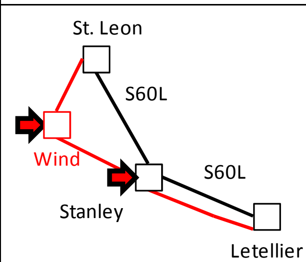
5.1. 230kV Transmission Plans

Power transfer limit analysis was performed on the 230kV transmission plans and wind generation injection points shown in Table 5-1.

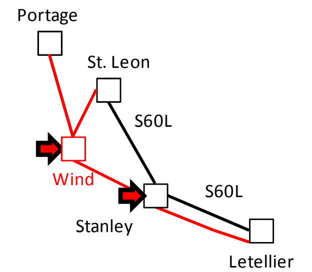
Table 5-1. Options studied in Power Transfer Limit Analysis (TLTG).

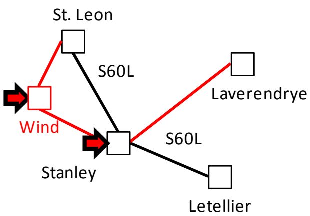
Option	***Wind Generation Injection***		***Diagram (red- new transmission) wind power injection***	***New Transmission***
	Pembina Escarpment	***Diversified Development***		
1	Stanley – 0-900MW	Stanley – 0-650MW Minnedosa – 0-150MW Glenboro – 0-100MW		none
2	St. Leon – 0-900MW	St. Leon – 0-650MW Minnedosa – 0-150MW Glenboro – 0-100MW		none
3	Stanley – 0-450MW St. Leon – 0-450MW	Stanley – 0-325MW St. Leon – 0-325MW Minnedosa – 0-150MW Glenboro – 0-100MW		none
4	New Wind – 0-450MW Stanley – 0-450MW	Stanley – 0-325MW St. Leon – 0-325MW Minnedosa – 0-150MW Glenboro – 0-100MW		230kV Wind-St.Leon (20km) 230kV Wind-Stanley (45km) Total: 65 km
4a	New Wind – 0-450MW Stanley – 0-450MW	Stanley – 0-325MW St. Leon – 0-325MW Minnedosa – 0-150MW Glenboro – 0-100MW		230kV Wind-St.Leon (20km) 230kV Wind-Stanley (45km) 230kV Wind-Portage (70km) Total: 135 km

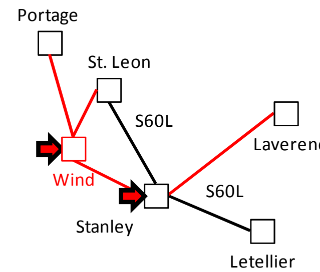
© TransGrid Solutions Inc, 2010

Option	Wind Generation Injection		Diagram (red- new transmission) wind power injection	New Transmission
	Pembina Escarpment	**Diversified Development**		
5	New Wind – 0-900MW	New Wind – 0-650MW Minnedosa – 0-150MW Glenboro – 0-100MW		230kV Wind-St.Leon (20km) 230kV Wind-Stanley (45km) Total: 65 km
5a	New Wind – 0-900MW	New Wind – 0-650MW Minnedosa – 0-150MW Glenboro – 0-100MW		230kV Wind-St.Leon (20km) 230kV Wind-Stanley (45km) 230kV Wind-Portage (70km) Total: 135 km
6	New Wind1 – 0-450MW New Wind2 – 0-450MW	New Wind1– 0-325MW New Wind2 – 0-325MW Minnedosa – 0-150MW Glenboro – 0-100MW		230kV Wind1-St.Leon (5km) 230kV Wind1-Wind2 (40km) 230kV Wind2-Stanley (20km) Total: 65 km
6a	New Wind1 – 0-450MW New Wind2 – 0-450MW	New Wind1– 0-325MW New Wind2 – 0-325MW Minnedosa – 0-150MW Glenboro – 0-100MW		230kV Wind1-St.Leon (5km) 230kV Wind1-Wind2 (40km) 230kV Wind2-Stanley (20km) 230kV Wind-Portage (70km) Total: 135 km
7	New Wind – 0-450MW Stanley – 0-450MW	New Wind– 0-325MW Stanley – 0-325MW Minnedosa – 0-150MW Glenboro – 0-100MW		230kV Wind-St.Leon (20km) 230kV Wind-Stanley (45km) 230kV Stanley-Letellier (65km) Total: 130 km

© TransGrid Solutions Inc, 2010

<table>
<tr><th rowspan="2">Option</th><th colspan="2">Wind Generation Injection</th><th rowspan="2">Diagram
(red- new transmission)
wind power injection</th><th rowspan="2">New Transmission</th></tr>
<tr><th>Pembina Escarpment</th><th>Diversified Development</th></tr>
<tr><td>7a</td><td>New Wind – 0-450MW
Stanley – 0-450MW</td><td>New Wind– 0-325MW
Stanley – 0-325MW
Minnedosa – 0-150MW
Glenboro – 0-100MW</td><td>
</td><td>230kV Wind-St.Leon (20km)
230kV Wind-Stanley (45km)
230kV Wind-Portage (70km)
230kV Stanley-Letellier (65km)

Total: 200 km</td></tr>
<tr><td>8</td><td>New Wind – 0-450MW
Stanley – 0-450MW</td><td>New Wind– 0-325MW
Stanley – 0-325MW
Minnedosa – 0-150MW
Glenboro – 0-100MW</td><td>
</td><td>230kV Wind-St.Leon (20km)
230kV Wind-Stanley (45km)
230kV Stanley-Laverendrye (70km)

Total: 135 km</td></tr>
<tr><td>8a</td><td>New Wind – 0-450MW
Stanley – 0-450MW</td><td>New Wind– 0-325MW
Stanley – 0-325MW
Minnedosa – 0-150MW
Glenboro – 0-100MW</td><td>
</td><td>230kV Wind-St.Leon (20km)
230kV Wind-Stanley (45km)
230kV Stanley-Laverendrye (70km)
230kV Wind-Portage (70km)

Total: 205 km</td></tr>
</table>

The TLTG analysis was performed for the summer peak cases with and without the new 500kV MH-US tie line. Summer peak is typically the most limiting condition in terms of thermal loading. Most overloads were found to be worse if only one 500kV MH-US tie line was in service.

There were three existing 230kV network lines that continuously were flagged for thermal loading:

- S53G – St. Leon to Glenboro
- P81C – Portage to Cornwallis
- S60L – Stanley to Letellier

Line S53G from St. Leon to Glenboro is overloaded during system intact and contingency conditions. Line S53G is a 230kV line comprised of 954 ACRS SC T7 conductor that is currently sagged to 75 deg C. It has a rating of 309.1 MVA , which is limited by the conductor. If the conductor were re-sagged to 100 deg C, the thermal rating of the line would increase to 419.5 MVA, an increase of 35.7%.

Line P81C from Portage to Cornwallis is overloaded following the loss of S53G for certain transmission plans. Line P81C is a 230kV line comprised of 795 ACSR 54/7 conductor that is currently sagged to 75 deg C. It has a rating of 283.6 MVA, which is limited by the conductor. If the conductor were re-sagged to 100 deg C, the thermal rating of the line would increase to 384.4 MVA, an increase of 35.5%.

Line S60L from Stanley to Letellier is overloaded during several contingency conditions. Line S60L has a thermal rating of 318.7 MVA and is currently limited by station equipment. If this station equipment were replaced the next limiting element becomes the line conductor, which is 954 ASCR SD T7 conductor sagged to 100 deg C. The line conductor is rated for 419.5 MVA, which would be an increase of 31.6%.

The TLTG analysis was re-run with these three upgrades in place to demonstrate the increase in generation injection associated with these upgrades.

© TransGrid Solutions Inc, 2010

Sections 5.1 through 5.4 present the results of the power transfer limit analysis, for the cases with and without the three network upgrades just discussed, for the cases with one and two 500kV MH-US tie lines, and for the Pembina Escarpment and Diversified Development scenarios. The values in the tables represent the wind generation level at which the particular thermal overload begins to occur. The starting point for the analysis assumed that there was a base level of 300 MW of wind (162 MW at St. Leon and 138 MW at St. Joseph) already in service. Therefore, if the power transfer limit results in the tables show overloads at wind generation levels of 300 MW or less, this means mitigation is required for the 600 MW wind scenario. If overloads are found at levels of 600 MW or less, mitigation is required for the 900 MW wind scenario. And similarly if overloads are found at levels of 900 MW or less, mitigation is required for the 1200 MW wind scenario.

The legend for the tables is as follows:

- Blue shaded: 600 MW wind scenario requires mitigation
- Green shaded: 900 MW wind scenario requires mitigation
- Purple shaded: 1200 MW wind scenario requires mitigation

5.1.1. 230kV Options 1-3

Options 1, 2 and 3 look at injecting up to 900 MW (Pembina Escarpment) and 650 MW (Diversified Development) of wind generation at Stanley, St. Leon and a combination of Stanley and St. Leon respectively. The Diversified Development plan also injects up to 150 MW at Neepawa and 100 MW at Glenboro. None of these options consider the addition of new transmission to the network. Simplified diagrams of the three options are shown in Figure 5-3. The results of the power transfer limit analysis are shown in Table 5-2.

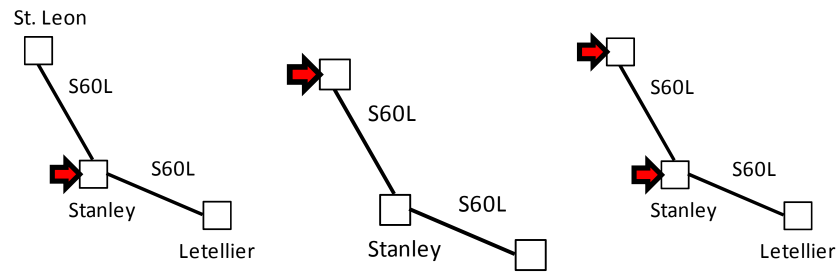


Figure 5-3. Transmission Options 1, 2 and 3 (left to right).

Table 5-2. Power Transfer Limit Results for Options 1-3.

Option	Pembina Escarpment				Diversified Development				Overloaded Line	Contingency
	1x500 kV lines		2x500 kV lines		1x500 kV lines		2x500 kV lines			
	No Upgr.	With Upgr.	No Upgr.	With Upgr.	No Upgr.	With Upgr.	No Upgr.	With Upgr.		
1	127.2	615.3	429.1	623.1	318.8	>900	>900	>900	S53G	L20D
	191.9	774.2	414.5	>900	575.7	>900	>900	>900		P81C or N54C
	420.6	579.6	450.6	610.3	586.6	808.3	627.1	849.3	S60L (Let-Stanley)	S53G
	564.9	735.9	550.5	723.3	726.1	>900	707.8	>900		G37C
	810.2	854.3	864.5	>900	>900	>900	>900	>900	S60L (Stan-StLeon)	L20D
2	84.3	475.9	285.0	603.6	166.0	803.3	552.2	>900	S53G	L20D
	115.2	408.0	201.1	430.5	191.4	575.5	332.6	711.9		S60L
	118.0	509.3	257.8	610.3	268.7	>900	514.4	>900		P81C or N54C
	509.2	557.6	571.4	619.4	712.5	780.2	796.9	836.9	S60L (Stan-StLeon)	S53G
	806.8	865.8	805.7	864.7	>900	>900	>900	>900		G37C
	610.8	841.6	654.4	886.3	854.6	>900	>900	>900	S60L (Let-Stan)	S53G
	842.4	842.4	790.0	790.0	>900	>900	>900	>900	D14S	S53G

© TransGrid Solutions Inc, 2010

3	146.1	589.5	317.9	752.6	389.0	>900	676.1	>900	S53G	P81C or N54C
	101.4	490.6	342.5	725.4	218.3	>900	721.9	>900		L20D
	498.1	686.4	533.7	722.9	695.7	>900	743.4	>900	S60L (Let-Stan)	S53G
	703.1	>900	685.3	>900	888.2	>900	866.0	>900		G37C

The mitigation required for Options 1-3 is summarized in Table 5-3. In general, the Diversified Development scenario requires fewer network upgrades than the Pembina Escarpment scenario.

Often the most limiting contingency for overloading line S53G is loss of line L20D. During MHEX south flow, loss of line L20D will result in a DC reduction. DC reduction is helpful to relieve some of the loading on line S53G. However, the TLTG analysis cannot implement DC reduction. Therefore the full steady state contingency analysis (PSSE activity ACCC) in Section 7 will further assess the impact of DC reduction on S53G overloading following the loss of L20D.

© TransGrid Solutions Inc, 2010

Table 5-3. Network Upgrades required for Options 1-3.

Wind Generation Level	Network Upgrades Required			
	1x500kV Lines		2x500kV Lines	
	Pembina Escarp.	Diversified Devel.	Pembina Escarp.	Diversified Devel.
Option 1 – Wind Generation injected at Stanley				
600 MW	-Resag S53G	None	None	None
900 MW	-Resag S53G -Reconductor S60L	-Resag S53G - Wavetrap Stanley	-Resag S53G - Wavetrap Stanley	None
1200 MW	-Reconductor S53G -Reconductor S60L	-Resag S53G - Wavetrap Stanley	Same as 1x500	- Wavetrap Stanley
Option 2 – Wind Generation injected at St. Leon				
600 MW	-Resag S53G	-Resag S53G	Same as 1x500	None
900 MW	-Reconductor S53G - Wavetrap Stanley	-Reconductor S53G	Same as 1x500	-Resag S53G
1200 MW	-Reconductor S53G -Reconductor S60L -Reconductor D14S	-Reconductor S53G -Recondcutor S60L (Stan-Let) - Wavetrap Stanley	Same as 1x500	-Reconductor S53G -Recondcutor S60L (Stan-Let)
Option 3 – Wind Generation injected at Stanley and St. Leon				
600 MW	-Resag S53G	-Resag S53G	None	None
900 MW	-Resag S53G -Reconductor S60L	-Resag S53G	-Resag S53G - Wavetrap Stanley	None
1200 MW	-Reconductor S53G -Reconductor S60L	-Resag S53G - Wavetrap Stanley	Same as 1x500	Same as 1x500

Options 1 and 3 appear to be a possibility for the 600 MW wind generation scenario as it only requires resagging of S53G if there is one 500kV MH-US tie line, and no upgrades if there are two 500kV MH-US tie lines. Option 2 is also a possibility but requires resagging of line S53G with one or two 500kV MH-US tie lines.

The 900 MW and 1200 MW scenarios begin to require line reconductoring, which is a more major upgrade.

5.1.2. 230kV Options 4-5

Options 4, 4a, 5 and 5a look at building a new 230kV wind collector station in the geopgraphic area between St. Leon and Stanley, and connecting this new station to St. Leon and Stanley via a 25 km and 40 km 230kV line, respectively. The “a” options look at the effect of also adding a 70 km 230kV line from the new wind collector station to Portage South. Option 4 injects up to 900 MW (Pembina Escarpment) or 650 MW (Diversified Development) of wind generation at a combination of Stanley and the new wind station, and Option 5 injects only at the new wind station. The Diversified Development plan also injects up to 150 MW at Neepawa and 100 MW at Glenboro. Simplified diagrams of the four options are shown in Figure 5-4. The results of the power transfer limit analysis are shown in Table 5-4.

© TransGrid Solutions Inc, 2010

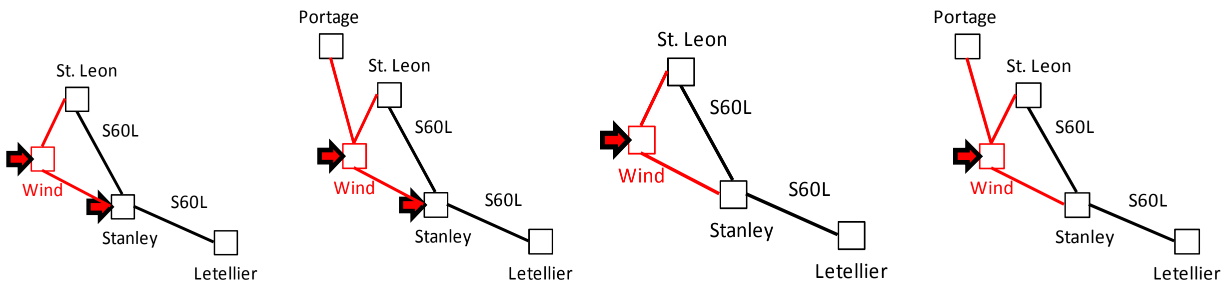


Figure 5-4. Transmission Options 4, 4a, 5 and 5a (left to right).

Table 5-4. Power Transfer Limit Results for Options 4-5.

Option	Pembina Escarpment				Diversified Development				Overloaded Line	Contingency
	1x500 kV lines		2x500 kV lines		1x500 kV lines		2x500 kV lines			
	No Upgr.	With Upgr.	No Upgr.	With Upgr.	No Upgr.	With Upgr.	No Upgr.	With Upgr.		
4	100.8	505.7	380.8	753.9	224.5	>900	773.4	>900	S53G	L20D
	161.6	628.4	339.6	797.0	467.1	>900	741.2	>900		P81C or N54C
	449.8	628.0	488.4	667.0	628.2	877.1	680.4	>900	S60L (Let-Stan)	S53G
	644.3	844.5	328.8	830.7	812.0	>900	792.6	>900		G37C
	838.6	838.6	838.9	838.9	>900	>900	>900	>900	Stanley-Wind	StL-Wind
	838.6	838.6	838.9	838.9	>900	>900	>900	>900	StLeon-Wind	Stan-Wind
4a	73.8	461.6	482.2	>900	255.8	>900	>900	>900	S53G	L20D
	52.6	676.0	348.4	>900	551.1	>900	>900	>900		P81C or N54C
	292.9	292.9	>900	>900	>900	>900	>900	>900	P81C	S53G
	644.3	894.5	714.4	>900	889.0	>900	>900	>900	S60L (Let-Stan)	S53G
	840.2	>900	856.5	>900	>900	>900	>900	>900		G37C
5	92.4	463.5	325.9	691.2	195.8	>900	676.9	>900	S53G	L20D
	145.7	566.6	307.0	712.5	680.0	>900	646.1	>900		P81C or N54C
	485.9	678.4	527.7	720.6	679.1	>900	735.4	>900	S60L (Let-Stan)	S53G
	715.3	>900	698.3	>900	892.7	>900	871.5	>900		G37C
	419.3	419.3	419.5	419.5	580.6	580.6	580.8	580.8	Stanley-Wind	StL-Wind
	419.3	419.3	419.5	419.5	580.6	580.6	580.8	580.8	StLeon-Wind	Stan-Wind
5a	72.0	659.1	470.1	>900	240.3	>900	>900	>900	S53G	L20D
	49.5	669.4	329.1	>900	270.7	>900	>900	>900		P81C
	229.0	229.0	>900	>900	>900	>900	>900	>900	P81C	S53G
	791.0	>900	876.8	>900	>900	>900	>900	>900	S60L (Let-Stan)	S53G
	678.5	678.5	714.4	714.4	>900	>900	>900	>900	Stanley-Wind	StL-Wind
	606.2	606.2	638.7	638.7	871.7	871.7	>900	>900	StLeon-Wind	Stan-Wind

The mitigation required for Options 4-5 is summarized in Table 5-5. In general, the Diversified Development scenario requires fewer network upgrades than the Pembina Escarpment scenario.

© TransGrid Solutions Inc, 2010

Table 5-5. Network Upgrades required for Options 4-5.

Wind Generation Level	***Network Upgrades Required***			
	1x500kV Lines		***2x500kV Lines***	
	Pembina Escarp.	***Diversified Devel.***	***Pembina Escarp.***	***Diversified Devel.***
Option 4 – Wind Generation injected at Stanley and Wind				
600 MW	-Resag S53G	-Resag S53G	None	None
900 MW	-Resag S53G -Wavetrap Stanley	-Resag S53G	-Resag S53G -Wavetrap Stanley	None
1200 MW	-Reconductor S53G -Wavetrap Stanley -Reconductor S60L -New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	-Resag S53G -Reconductor S60L (Let-Stan)	Same as 1x500	-Resag S53G -Wavetrap Stanley
Option 4a – Wind Generation injected at Stanley and Wind, with Portage-Wind line				
600 MW	-Resag S53G -Resag P81C	-Resag S53G	None	None
900 MW	-Reconductor S53G -Resag P81C	-Resag S53G	-Resag S53G	None
1200 MW	-Reconductor S53G -Resag P81C -Wavetrap Stanley -Reconductor S60L	-Resag S53G -Wavetrap Stanley	-Resag S53G -Wavetrap Stanley	None
Option 5 – Wind Generation injected at Wind				
600 MW	-Resag S53G	-Resag S53G	None	None
900 MW	-Reconductor S53G -Wavetrap Stanley -New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	-Resag S53G -New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	-Resag S53G -Wavetrap Stanley - New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	-New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA
1200 MW	-Reconductor S53G -Wavetrap Stanley -Reconductor S60L -New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	-Resag S53G -Wavetrap Stanley -New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	Same as 1x500	Same as 1x500
Option 5a – Wind Generation injected at Wind, with Portage-Wind line				
600 MW	-Resag S53G -Resag P81C	-Resag S53G	None	None
900 MW	-Resag S53G -Resag P81C	-Resag S53G	-Resag S53G	None
1200 MW	-Reconductor S53G -Wavetrap Stanley -Reconductor S60L -New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	-Resag S53G -New Wind- StLeon>419.5MVA	-Resag S53G - Wavetrap Stanley -New Wind- StLeon>419.5MVA -New Wind- Stanley>419.5MVA	None

© TransGrid Solutions Inc, 2010

5.1.3. 230kV Option 6

Options 6 and 6a look at building two new 230kV wind collector stations in the geographic area between St. Leon and Stanley, and connecting these new stations to each other and one each to St. Leon and Stanley. This will require three new 230kV lines with lengths of 5 km, 40 km and 20 km. The “a” option looks at the effect of also adding a 70 km 230kV line from one of the new wind collector stations to Portage South. Option 6 injects up to 900 MW (Pembina Escarpment) or 650 MW (Diversified Development) of wind generation at a combination of the two new wind collector stations. The Diversified Development plan also injects up to 150 MW at Neepawa and 100 MW at Glenboro. Simplified diagrams of the two options are shown in Figure 5-5. The results of the power transfer limit analysis are shown in Table 5-6.

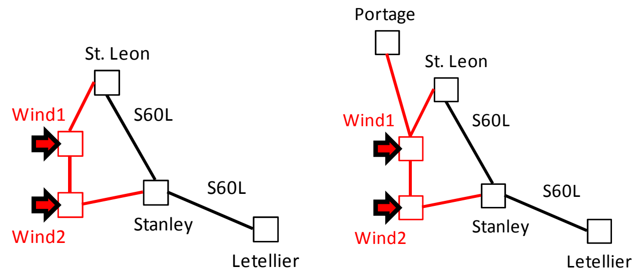


Figure 5-5. Transmission Options 6 and 6a (left to right).

Table 5-6. Power Transfer Limit Results for Option 6.

Option	*Pembina Escarpment*				*Diversified Development*				*Overloaded Line*	*Contingency*
	1x500 kV lines		*2x500 kV lines*		*1x500 kV lines*		*2x500 kV lines*			
	No Upgr.	*With Upgr.*	*No Upgr.*	*With Upgr.*	*No Upgr.*	*With Upgr.*	*No Upgr.*	*With Upgr.*		
6	92.4	463.5	325.9	691.2	195.8	>900	676.9	>900	S53G	L20D
	145.7	566.6	307.0	715.3	380.0	>900	646.1	>900		P81C or N54C
	485.9	678.4	527.7	720.6	679.1	>900	735.4	>900	S60L (Let-Stan)	S53G
	715.3	>900	698.3	>900	892.7	>900	871.5	>900		G37C
	419.2	419.5	419.4	419.4	580.4	580.4	580.9	580.9	Stan-Wind2	StLeon-Wind1
	838.4	838.4	838.8	838.8	>900	>900	>900	>900		Wind 1-2
	419.5	419.5	419.6	419.6	580.9	580.9	580.7	580.7	StLeon-Wind1	Stan-Wind2
	839.0	839.0	839.0	839.0	>900	>900	>900	>900	Wind1-2	Stan-Wind2
6a	54.1	580.9	423.8	>900	161.2	>900	>900	>900	S53G	L20D
	24.9	601.2	290.5	854.2	118.1	>900	>900	>900		P81C
	248.6	248.6	>900	>900	>900	>900	>900	>900	P81C	S53G
	703.5	>900	776.1	>900	>900	>900	>900	>900	S60L (Let-Stan)	S53G
	629.7	629.7	659.2	659.2	885.9	885.9	>900	>900	Stan-Wind2	StLeon-Wind 1
	838.4	838.4	838.6	838.6	>900	>900	>900	>900		Wind 1-2
	508.8	508.8	540.9	540.9	731.6	731.6	776.7	776.7	StLeon-Wind1	Stan-Wind 2
	839.1	839.1	839.1	839.1	>900	>900	>900	>900	Wind 1-2	Stan-Wind 2

The mitigation required for Option 6 is summarized in Table 5-7. In general, the Diversified Development scenario requires fewer network upgrades than the Pembina Escarpment scenario.

© TransGrid Solutions Inc, 2010

Table 5-7. Network Upgrades required for Option 6.

Wind Generation Level	Network Upgrades Required			
	1x500kV Lines		2x500kV Lines	
	Pembina Escarp.	Diversified Devel.	Pembina Escarp.	Diversified Devel.
Option 6 – Wind Generation injected at Two New Wind Stations				
600 MW	-Resag S53G	-Resag S53G	None	None
900 MW	-Reconductor S53G -Wavetrap Stanley -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA	-Resag S53G -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA	Same as 1x500	-New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA
1200 MW	-Reconductor S53G -Wavetrap Stanley -Reconductor S60L -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA -New Wind1-2 > 419.5 MVA	-Resag S53G -Wavetrap Stanley -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA	Same as 1x500	Same as 1x500
Option 6a – Wind Generation injected at Two New Wind Stations, with Portage-Wind line				
600 MW	-Resag S53G -Resag P81C	-Resag S53G	-Resag S53G	None
900 MW	-Reconductor S53G -Resag P81C -New Wind-StLeon>419.5MVA	-Resag S53G	-Resag S53G -New Wind-StLeon>419.5MVA	None
1200 MW	-Reconductor S53G -Resag P81C -Wavetrap Stanley -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA -New Wind1-2 > 419.5 MVA	-Resag S53G -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA	-Resag S53G -Wavetrap Stanley -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA -New Wind1-2 > 419.5 MVA	-New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA

© TransGrid Solutions Inc, 2010

5.1.4. 230kV Options 7-8

Options 7, 7a, 8 and 8a look at building a new 230kV wind collector station in the geographic area between St. Leon and Stanley, and connecting this new station to St. Leon and Stanley via a 25 km and 40 km 230kV line, respectively. In addition, a new 230kV line out of Stanley is added; in Option 7 this line goes to Letellier, and in Option 8 this line goes to Laverendrye. The “a” options look at the effect of also adding a 70 km 230kV line from the new wind collector station to Portage South. All options inject up to 900 MW (Pembina Escarpment) or 650 MW (Diversified Development) of wind generation at a combination of Stanley and the new wind station. The Diversified Development plan also injects up to 150 MW at Neepawa and 100 MW at Glenboro. Simplified diagrams of the four options are shown in Figure 5-6. The results of the power transfer limit analysis are shown in Table 5-8.

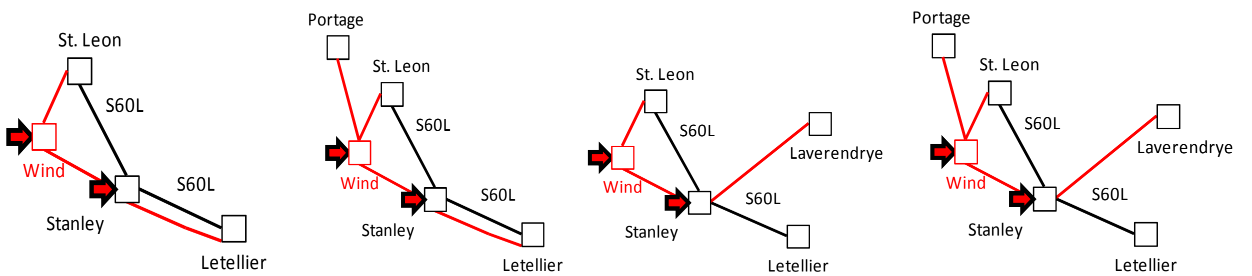


Figure 5-6. Transmission Options 7, 7a, 8 and 8a (left to right).

Table 5-8. Power Transfer Limit Results for Options 7-8.

Option	*Pembina Escarpment*				*Diversified Development*				*Overloaded Line*	*Contingency*
	1x500 kV lines		*2x500 kV lines*		*1x500 kV lines*		*2x500 kV lines*			
	No Upgr.	*With Upgr.*	*No Upgr.*	*With Upgr.*	*No Upgr.*	*With Upgr.*	*No Upgr.*	*With Upgr.*		
7	75.2	521.3	361.7	800.7	181.9	>900	850.4	>900	S53G	L20D
	159.9	689.4	357.7	875.6	487.0	>900	843.0	>900	S53G	P81C
	720.8	>900	759.2	>900	>900	>900	>900	>900	S60L (Let-Stan)	S53G
	814.4	>900	826.9	>900	>900	>900	>900	>900		Stan-Let
	838.8	838.8	839.0	839.0	>900	>900	>900	>900	Stanley-Wind	Wind 1-2
	838.8	838.8	839.0	839.0	>900	>900	>900	>900	StLeon-Wind	Stan-Wind
7a	44.6	699.0	492.8	>900	183.1	>900	>900	>900	S53G	L20D
	47.2	782.0	367.7	>900	656.2	>900	>900	>900	S53G	P81C
	356.0	356.0	>900	>900	>900	>900	>900	>900	P81C	S53G
8	35.4	564.3	383.1	>900	103.8	>900	>900	>900	S53G	L20D
	61.7	670.8	331.3	>900	305.4	>900	887.9	>900	S53G	P81C
	600.5	870.8	697.2	>900	847.0	>900	>900	>900	S60L (Let-Stan)	S53G
	822.6	>900	859.4	>900	>900	>900	>900	>900		G37C
	838.8	838.8	839.0	839.0	>900	>900	>900	>900	Stanley-Wind	Wind 1-2
	838.8	838.8	839.0	839.0	>900	>900	>900	>900	StLeon-Wind	Stan-Wind
8a	-1.2	758.1	465.2	>900	446.7	>900	>900	>900	S53G	L20D
	-61.8	761.6	338.1	>900	>900	>900	>900	>900	S53G	P81C
	813.9	>900	>900	>900	>900	>900	>900	>900	S60L (Let-Stan)	S53G

The mitigation required for Options 7-8 is summarized in Table 5-9. In general, the Diversified Development scenario requires fewer network upgrades than the Pembina Escarpment scenario.

© TransGrid Solutions Inc, 2010

Table 5-9. Network Upgrades required for Options 7-8.

Wind Generation Level	Network Upgrades Required			
	1x500kV Lines		2x500kV Lines	
	Pembina Escarp.	Diversified Devel.	Pembina Escarp.	Diversified Devel.
Option 7 – Wind Generation injected at Stanley and Wind, new Stanley-Letellier				
600 MW	-Resag S53G	-Resag S53G	None	None
900 MW	-Reconductor S53G	-Resag S53G	-Resag S53G	None
1200 MW	-Reconductor S53G -Wavetrap Stanley -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA	-Resag S53G	Same as 1x500	-Resag S53G
Option 7a – Wind Generation injected at Stanley and Wind, new Stanley-Letellier, with Portage-Wind line				
600 MW	-Resag S53G	-Resag S53G	None	None
900 MW	-Resag S53G -Resag P81C	-Resag S53G	-Resag S53G	None
1200 MW	-Reconductor S53G -Resag P81C	-Resag S53G	-Resag S53G	None
Option 8 – Wind Generation injected at Stanley and Wind, new Stanley-Laverendrye				
600 MW	-Resag S53G	-Resag S53G	None	None
900 MW	-Reconductor S53G	-Resag S53G	-Resag S53G	None
1200 MW	-Reconductor S53G -Wavetrap Stanley -Reconductor S60L -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA	-Resag S53G -Wavetrap Stanley	-Resag S53G -Wavetrap Stanley -New Wind-StLeon>419.5MVA -New Wind-Stanley>419.5MVA	-Resag S53G
Option 8a – Wind Generation injected at Stanley and Wind, new Stanley-Laverendrye, with Portage-Wind line				
600 MW	-Resag S53G	None	None	None
900 MW	-Resag S53G	-Resag S53G	-Resag S53G	None
1200 MW	-Reconductor S53G -Wavetrap Stanley	-Resag S53G	-Resag S53G	None

© TransGrid Solutions Inc, 2010

5.2. Breakpoints For Network Upgrades

It is useful to note the generation breakpoints at which major network upgrades would be required. The generation breakpoints depend on several factors, including:

- One or two 500 kV MH-US lines in service (the breakpoints are higher when there are two)
- Pembina Escarpment or Diversified Development scenario (the breakpoints are higher for the Diversified Development scenario)
- The transmission plans and wind generation injection points being considered

Table 5-10 provides a very approximate range of breakpoints for the wind generation. The range is due to the various transmission plans and wind generation points under consideration. Transmission Option 2 is excluded in some cases as it is often an outlier with the lowest breakpoint. Note that these breakpoints assume there is already 300 MW of wind generation in service; 162 MW at St. Leon and 138 MW at St. Joseph. The breakpoints in Table 5-10 are <u>in addition</u> to this 300 MW.

Table 5-10. Range of generation breakpoints for various network upgrades.

Upgrade Required	*Pembina Escarpment*		*Diversified Development*	
	1-500kV MH-US lines	*2-500kV MH-US lines*	*1-500kV MH-US lines*	*2-500kV MH-US lines*
Line S53G resag	0-150	200-480	170-450	670->900*
Line S53G reconductor	450-700	600->900	>900*	>900*
Line S60L reconductor	580-900	600->900	800->900	850->900

*excluding Option 2

5.3. Summary of 230kV Transmission Plan Development

The results of the steady state analysis are quite dependent on whether there are one or two 500kV MH-US tie lines. Fewer network upgrades are required for the case with two 500kV MH-US tie lines. Similarly, fewer network upgrades are required for the Diversified Development wind scenario compared to the Pembina Escarpment wind scenario.

In the end, it is desirable to choose a transmission plan with the best combination of the following:

- Lowest cost
- Least new transmission to be built
- Lowest losses
- Least adverse/ most positive impact to the MH-US tie line power flow
- Best dynamic system performance
- Least adverse / most positive impact to system short circuit levels
- A plan that makes sense to be staged from 300 MW up to 1200 MW of wind generation

Therefore at this stage of the report, it is not yet possible to finalize the best transmission plan, however one or two of the options are chosen at the end of this section for the 600 MW, 900 MW and 1200 MW wind scenarios. These options are analysed and discussed in more detail throughout the rest of the report.

5.3.1. 600 MW Wind Scenario

Table 5-11 summarizes the network upgrades required for the 600 MW wind scenario for each of the transmission options. The legend for the check marks is as follows:

- Black – Pembina Escarpment with one 500 kV MH-US Tie Line
- Red - Pembina Escarpment with two 500 kV MH-US Tie Lines
- Blue – Diversified Development with one 500 kV MH-US Tie Line
- Purple – Diversified Development with one 500 kV MH-US Tie Line

© TransGrid Solutions Inc, 2010

Table 5-11. Upgrades required for 600 MW Wind Scenarios.

Option	*Stn Equip S60L*	*Resag S53G*	*Resag P81C*	*Recon-ductor S53G*	*Recon-ductor S60L*	*Build new 230 kV > 419.5 MVA*	*# New 230kV Lines*	*Total Length new 230kV lines*	*# New Stations*
Pembina 1x500, Pembina 2x500, Diversified 1x500, Diversified 2x500									
1		√					0	0	0
2		√ √ √					0	0	0
3		√ √					0	0	0
4		√ √					2	65	1
4a		√ √	√				3	135	1
5		√ √					2	65	1
5a		√ √	√				3	135	1
6		√ √					3	65	2
6a		√ √ √	√				4	135	2
7		√ √					3	130	1
7a		√ √	√				4	200	1
8		√ √					3	135	1
8a		√					4	205	1

For the 600 MW wind generation scenario, it is not necessary to build any new 230kV network transmission. The preferred transmission plan would likely be Option 1, which involves the interconnection of the additional wind generation at the Stanley station. The only scenario that requires a network upgrade is the Pembina Escarpment plan in the case if only one 500kV MH-US tie line is in-service. This case requires line S53G to be resagged. No network upgrades are needed if there are two 500kV MH-US tie lines. From this point forward, this option will be referred to as 600 MW Transmission Plan 1. It is shown in Figure 5-7.

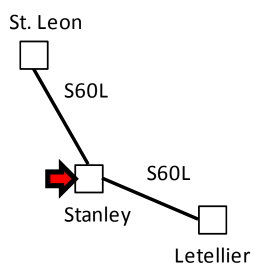


Figure 5-7. 600 MW Transmission Plan 1.

600 MW Transmission Plan 1 are further analyzed throughout this report for the 600 MW wind scenarios.

5.3.2. 900 MW Wind Scenario

Table 5-12 summarizes the network upgrades required for the 900 MW wind scenario. The legend for the check marks is the same as Table 5-11.

© TransGrid Solutions Inc, 2010

Table 5-12. Upgrades required for 900 MW Wind Scenarios.

Option	*Stn Equip S60L*	*Resag S53G*	*Resag P81C*	*Recon-ductor S53G*	*Recon-ductor S60L*	*Build new 230 kV > 419.5 MVA*	*# New 230kV Lines*	*Total Length new 230kV lines*	*# New Stations*
Pembina 1x500, Pembina 2x500, Diversified 1x500, Diversified 2x500									
1	√ √ √	√ √ √			√		0	0	0
2	√ √ √	√		√ √ √			0	0	0
3	√ √	√ √ √			√		0	0	0
4	√ √	√ √		√			2	65	1
4a		√ √	√	√			3	135	1
5	√ √	√ √		√		√ √ √	2	65	1
5a		√ √ √	√			√	3	135	1
6	√ √	√		√ √		√ √ √ √	3	65	2
6a		√ √	√	√		√ √	4	135	2
7		√ √		√			3	130	1
7a		√ √ √	√				4	200	1
8		√ √		√			3	135	1
8a		√ √ √					4	205	1

For the 900 MW wind generation scenario, it is possible to avoid building any new 230kV network transmission, however this would require reconductoring of line S60L for the Pembina Escarpment wind scenario if there is only one 500kV MH-US tie line. The preferred option for building no new 230kV network transmission would again be Option 1. In all cases, except the Diversified development plan with two 500kV MH-US tie lines, line S53G would need to be resagged and station equipment replacement would be required on the Stanley-Letellier portion of line S60L.

Alternatively, a new 230kV wind collector station could be built between and connected to Stanley and St. Leon, as in Option 4. This plan avoids the need to reconductor line S60L. However, for the Pembina Escarpment wind scenario if there is only one 500kV MH-US tie line, line S53G would need to be reconductored. The Diversified Development plan with two 500kV MH-US tie lines would need no network upgrades. From this point forward, these options will be referred to as 900 MW Transmission Plan 1 and Plan 2. They are shown in Figure 5-8.

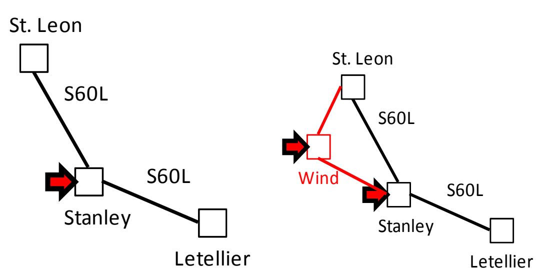


Figure 5-8. 900 MW Transmission Plan 1 (left) and 2 (right).

900 MW Transmission Plan 1 and 2 are further analyzed throughout this report for the 900 MW wind scenarios.

5.3.3. 1200 MW Wind Scenario

Table 5-13 summarizes the network upgrades required for the 1200 MW wind scenario. The legend for the check marks is the same as Table 5-11.

© TransGrid Solutions Inc, 2010

Table 5-13. Upgrades required for 1200 MW Wind Scenarios.

Option	*Stn Equip S60L*	*Resag S53G*	*Resag P81C*	*Recon-ductor S53G*	*Recon-ductor S60L*	*Build new 230 kV > 419.5 MVA*	*# New 230kV Lines*	*Total Length new 230kV lines*	*# New Stations*
Pembina 1x500, Pembina 2x500, Diversified 1x500, Diversified 2x500									
1	√ √ √ √	√		√ √	√ √ √ √		0	0	0
2	√ √ √ √			√ √ √ √	√ √ √ √		0	0	0
3	√ √ √ √	√ √		√ √	√ √		0	0	0
4	√ √ √ √	√ √		√ √	√ √ √	√ √	2	65	1
4a	√ √ √	√ √	√	√	√		3	135	1
5	√ √ √ √	√ √		√ √	√ √	√ √ √ √	2	65	1
5a	√ √	√ √		√		√ √ √	3	135	1
6	√ √ √ √	√ √		√ √	√ √	√ √ √ √	3	65	2
6a	√ √	√ √	√	√		√ √ √ √	4	135	2
7	√ √ √	√		√ √		√ √	3	130	1
7a		√ √	√	√			4	200	1
8	√ √ √	√ √ √		√	√	√ √	3	135	1
8a	√	√ √		√			4	205	1

For the 1200 MW wind generation scenario, it appears possible to avoid building any new 230kV network transmission, however this would require reconductoring of both lines S53G and S60L. In addition, 1200 MW seems rather large, especially for the Pembina Escarpment in which a 900 MW wind power injection would occur into a single or two locations without any new transmission. Stability wise this may be an issue.

It is assumed that at least some new transmission would be necessary for the 1200 MW wind scenario. In that case, the minimum transmission Option 4 (65 km) as well an option with more transmission, Option 7a (200 km), are further analyzed throughout this report for the 1200 MW wind scenarios in order to show the feasibility of a range of transmission options. From this point forward, these options will be referred to as 1200 MW Transmission Plan 1 and Plan 2. They are shown in Figure 5-9.

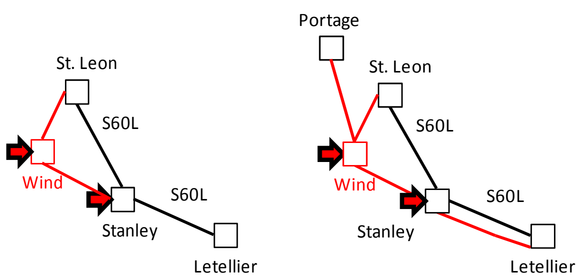


Figure 5-9. 1200 MW Transmission Plan 1 (left) and 2 (right).

5.4. 500kV Transmission Plan

In order to be considered for analysis, a 500kV option should have not much more than half of the length of new transmission than a comparable 230kV solution in order to be economically comparable (due to the higher costs associated with 500kV). The steady state analysis of the 230kV options showed the plan with the highest length of new 230kV transmission to be 205 km, and such an option would really only need to be considered at 1200 MW, not at lower wind generation. Therefore, the only 500kV option that was considered in this study was a radial 500kV line from the new wind generation area near St. Leon to the 500kV Dorsey station.

This 500kV option is shown in Figure 5-10. In this plan only one new 230kV wind collector station is built into which all of the new 900 MW of wind farms are collected. The 230kV station is connected to a 500kV line via two 230-500kV step-up transformers. A 128km 500kV radial transmission line connects the wind collector station to the Dorsey 500kV station. The drawback of this particular transmission plan is that it is

© TransGrid Solutions Inc, 2010

less reliable than the meshed 230kV plans. If the 500kV wind-Dorsey line trips, all of the wind generation is lost.

Figure 5-10. 500kV Radial Transmission Plan.

The 1200 MW wind scenario with the 500kV transmission plan showed no thermal overload or voltage violation impacts compared to the base case. This makes sense as the new wind generation in this transmission plan is feeding directly into Dorsey, while being offset to the HVDC infeed at Dorsey via reduced northern generation at Keeyask and Conawapa. From a power flow perspective, the base case and the 500kV option with the wind scenario are nearly the same.

© TransGrid Solutions Inc, 2010

6. Transmission Plans for Detailed Study

As summarized in Sections 5.5 and 5.6, the following transmission plans are analyzed in more detail throughout this report. It is not meant to say that these are necessarily the best of the plans, they are simply a subset that will be analyzed in more detail since would be impractical in this study to perform detailed analysis of each of the options presented in Section 5 for both the Pembina Escarpment and Diversified Development wind scenarios.

600 MW

- 230kV Transmission Plan 1

900 MW

- 230kV Transmission Plan 1
- 230kV Transmission Plan 2

1200 MW

- 230kV Transmission Plan 1
- 230kV Transmission Plan 2
- Radial 500kV Transmission Plan

This section discusses these transmission plans in more detail, including the approximate lengths of new 230kV transmission that will be required to directly connect each new wind farm to its connection point in the grid.

6.1. 600 MW Wind Scenario

600 MW Transmission Plan 1 is shown in Figures 6-1 and 6-2 for the Pembina Escarpment and Diversified Development plans, respectively.

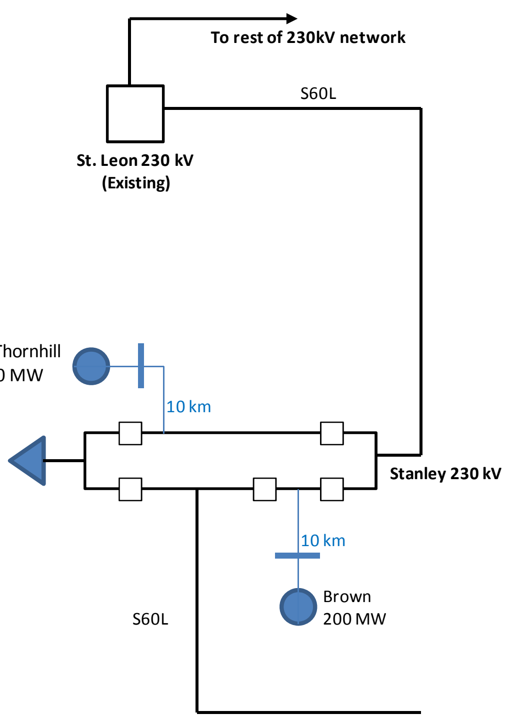


Figure 6-1. 600 MW Pembina Escarpment Plan – Transmission Plan 1.

© TransGrid Solutions Inc, 2010

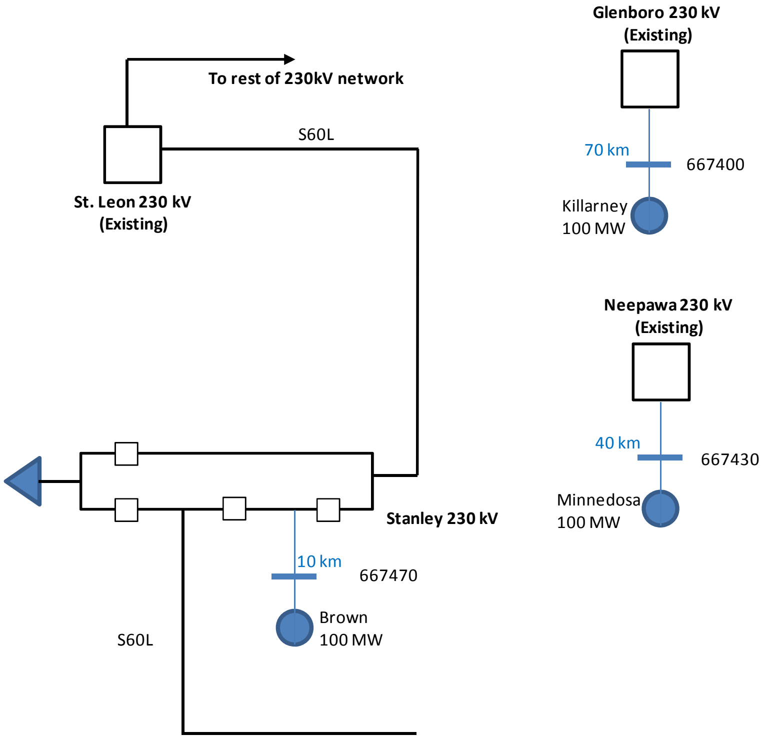


Figure 6-2. 600 MW Diversified Development Plan – Transmission Plan 1.

The details of the 600 MW transmission plans are summarized in Table 6-1.

Table 6-1. Details of 600 MW Transmission Plan 1.

Wind Farm	*Size (MW)*	*Length 230kV Radial Feeders (km)*	*Length New Network Transmission (km)*	*# New 230kV Breaker Terminations in Ring Bus*
600 MW Pembina Escarpment				
South Thornhill Brown	100 200	10 10	0	5
600 MW Diversified Development				
Brown Killarney Minnedosa	100 100 100	10 70 40	0	6

The Pembina Escarpment scenario investigated for 600 MW Transmission Plan 1 involves two wind farms, each with 10 km 230kV radial feeders, for a total of 20 km of new 230kV transmission. The Stanley station would need to be expanded to a five 230kV breaker ring bus.

The Diversified Development scenario investigated for 600 MW Transmission Plan 1 involves three wind farms, with 230kV feeder lengths of 10 km, 70 km and 40 km, for a total of 120 km of new 230kV transmission. The Stanley station would need to be expanded to a four 230kV breaker ring bus. An additional 230kV breaker termination would be required at both the Neepawa and Glenboro 230kV stations as well, for a total of six new 230kV breaker terminations.

6.2. 900 MW Wind Scenario

900 MW Transmission Plans 1 and 2 are shown in Figures 6-3 and 6-4 for the Pembina Escarpment and Diversified Development plans, respectively.

© TransGrid Solutions Inc, 2010

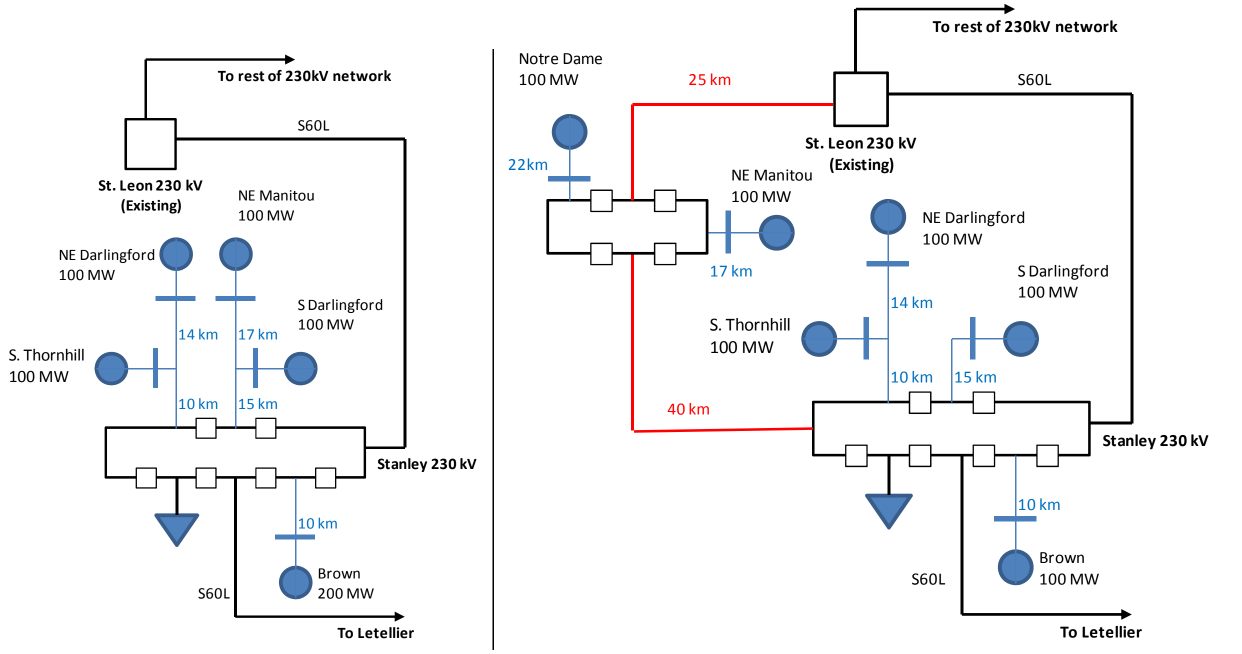


Figure 6-4. 900 MW Pembina Escarpment Plan – Transmission Plan 1 (left) and 2 (right).

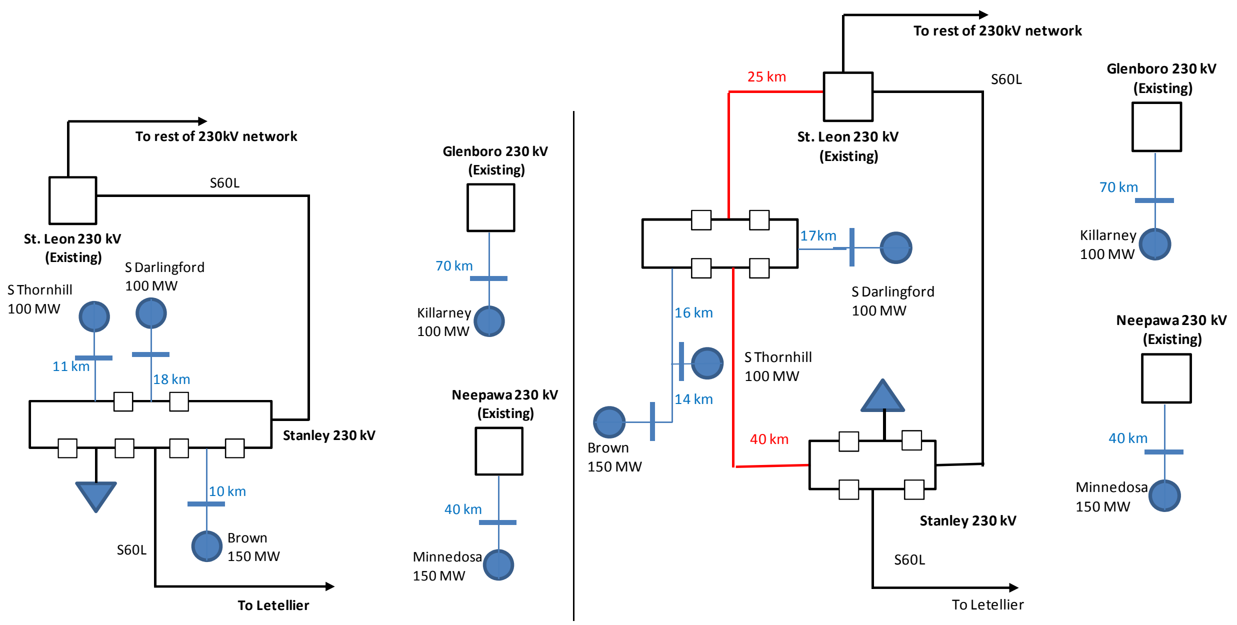


Figure 6-4. 900 MW Diversified Development Plan – Transmission Plan 1 (left) and 2 (right).

The details of the 900 MW plans are summarized in Table 6-2.

© TransGrid Solutions Inc, 2010

Table 6-2. Details of 900 MW Transmission Plans 1 and 2.

Wind Farm	*Size (MW)*	*Length 230kV Radial Feeders (km)*	*Length New Network Transmission (km)*	*# New 230kV Breaker Terminations in Ring Bus*
900 MW Pembina Escarpment – Transmission Plan 1				
NE Darlingford	100	14	0	6
S Thornhill	100	15		
S Darlingford	100	15		
NE Manitou	100	17		
Brown	200	10		
Total	600	71	0	6
900 MW Pembina Escarpment – Transmission Plan 2				
Notre Dame	100	22	65	11
NE Manitou	100	17		
NE Darlingford	100	14		
S Thornhill	100	10		
S Darlingford	100	15		
Brown	100	10		
Total	600	88	65	11
900 MW Diversified Development – Transmission Plan 1				
S Thornhill	100	11	0	8
S Darlingford	100	18		
Brown	150	10		
Killarney	100	70		
Minnedosa	150	40		
Total	600	149	0	8
900 MW Diversified Development – Transmission Plan 2				
Brown	150	14	65	11
S Thornhill	100	16		
S Darlingford	100	17		
Killarney	100	70		
Minnedosa	150	40		
Total	600	157	65	11

Pembina Escarpment 900 MW Transmission Plan 1 involves five wind farms, with a total length of 71 km of 230kV radial feeders. No new network transmission is added. The Stanley station would need to be expanded to a six 230kV breaker ring bus.

Pembina Escarpment 900 MW Transmission Plan 2 involves six wind farms, with a total length of 88 km of new 230kV radial feeders. In addition, 65 km of new 230kV network transmission is added. The Stanley station would need to be expanded to a six 230kV breaker ring bus. A new four breaker 230kV wind collector station is built between Stanley and St. Leon. One new 230kV breaker termination is also required at St. Leon, for a total of eleven new 230kV breaker terminations.

Diversified Development 900 MW Transmission Plan 1 involves five wind farms, with a total length of 149 km of new 230kV radial feeders. No new network transmission is added. The Stanley station would need to be expanded to a six 230kV breaker ring bus. An additional 230kV breaker termination would be required at both the Neepawa and Glenboro 230kV stations as well, for a total of eight new 230kV breaker terminations.

Diversified Development 900 MW Transmission Plan 2 involves five wind farms, with a total length of 157 km of new 230kV radial feeders. In addition, 65 km of new 230kV network transmission is added. The Stanley station would need to be expanded to a four 230kV breaker ring bus. A new four breaker 230kV wind collector station is built between Stanley and St. Leon. One new 230kV breaker termination is also

© TransGrid Solutions Inc, 2010

required at St. Leon. An additional 230kV breaker termination would be required at both the Neepawa and Glenboro 230kV stations as well, for a total of eleven new 230kV breaker terminations.

6.3. 1200 MW

1200 MW Transmission Plans 1 and 2 are shown in Figures 6-5 and 6-6 for the Pembina Escarpment and Diversified Development plans, respectively.

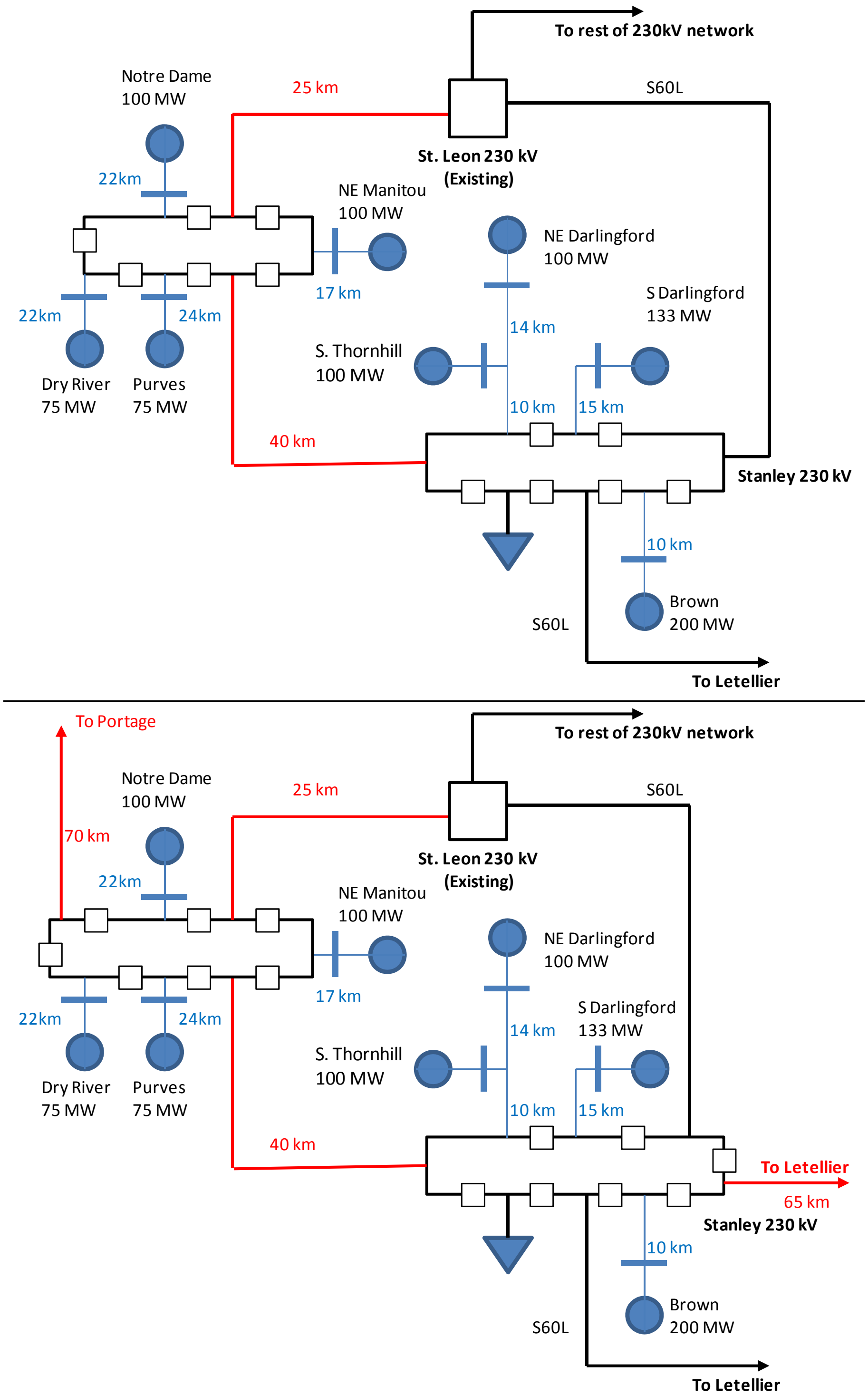


Figure 6-5. 1200 MW Pembina Escarpment Plan – Transmission Plan 1 (top) and 2 (bottom).

© TransGrid Solutions Inc, 2010

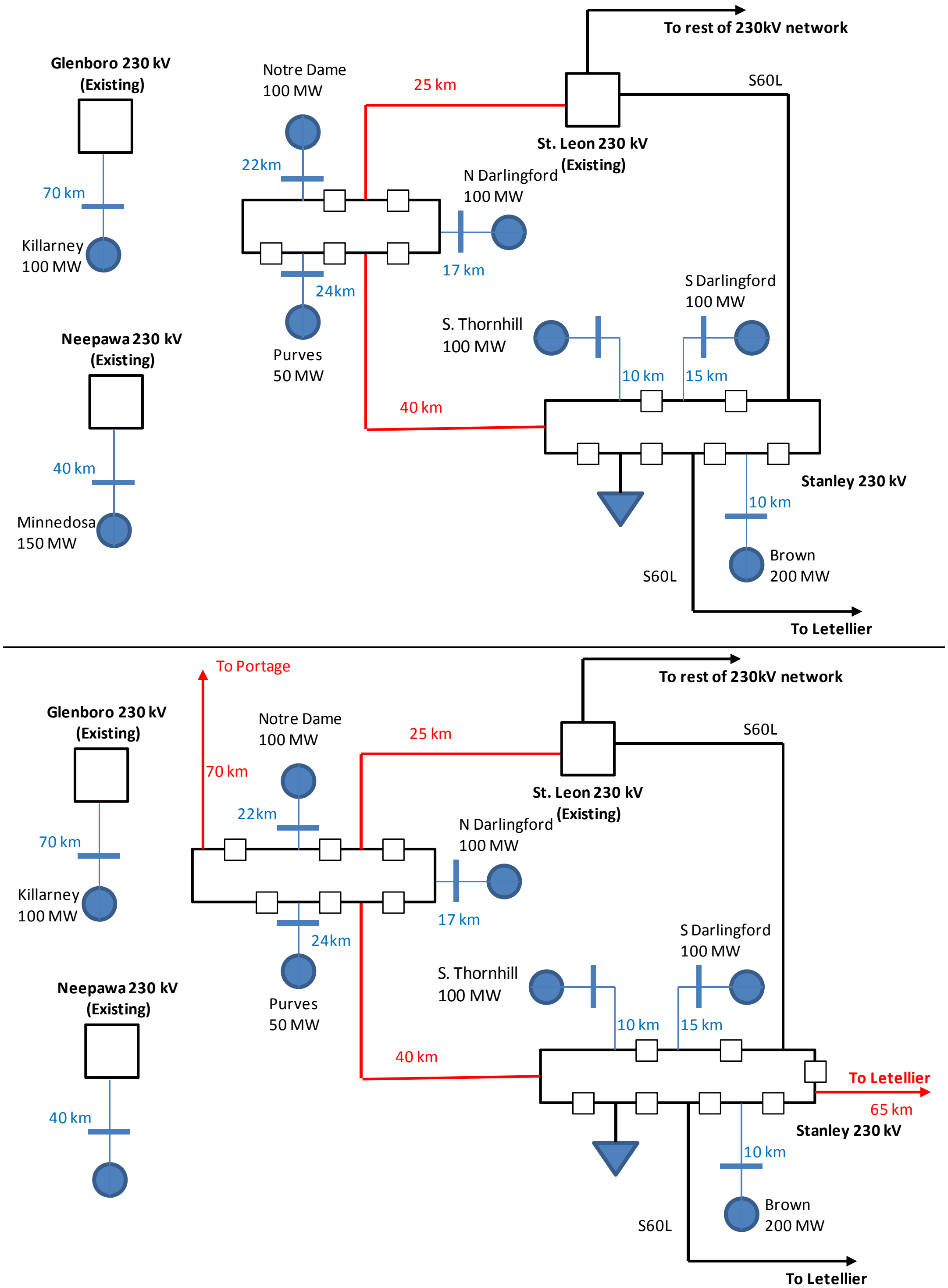


Figure 6-6. 1200 MW Diversified Development Plan – Transmission Plan 1 (top) and 2 (bottom).

The details of the 1200 MW plans are summarized in Table 6-3.

© TransGrid Solutions Inc, 2010

Table 6-3. Details of 1200 MW Transmission Plans 1 and 2.

Wind Farm	***Size (MW)***	***Length 230kV Radial Feeders (km)***	***Length New Network Transmission (km)***	***# New 230kV Breaker Terminations in Ring Bus***
1200 MW Pembina Escarpment – Option 4				
NE Darlingford	100	14	65	13
S Thornhill	100	10		
S Darlingford	100	15		
Brown	200	10		
Notre Dame	100	22		
NE Manitou	100	17		
Dry River	75	22		
Purves	75	24		
Total	900	134	65	13
1200 MW Pembina Escarpment – Option 7a				
NE Darlingford	100	14	200	16
S Thornhill	100	10		
S Darlingford	100	15		
Brown	200	10		
Notre Dame	100	22		
NE Manitou	100	17		
Dry River	75	22		
Purves	75	24		
NE Darlingford	100	14		
Total	900	134	200	16
1200 MW Diversified Development – Option 4				
NE Darlingford	100	17	65	14
S Thornhill	100	10		
S Darlingford	100	15		
Brown	200	10		
Notre Dame	100	22		
Killarney	100	70		
Minnedosa	150	40		
Purves	50	24		
Total	900	208	65	14
1200 MW Diversified Development – Option 7a				
NE Darlingford	100	17	200	16
S Thornhill	100	10		
S Darlingford	100	15		
Brown	200	10		
Notre Dame	100	22		
Killarney	100	70		
Minnedosa	150	40		
Purves	50	24		
Total	900	208	200	16

Pembina Escarpment 1200 MW Transmission Plan 1 involves eight wind farms, with a total length of 134 km of new 230kV radial feeders. In addition, 65 km of new network transmission is added. The Stanley station would need to be expanded to a six 230kV breaker ring bus. A new six breaker 230kV wind collector station is built between Stanley and St. Leon. One new 230kV breaker termination is also required at St. Leon, for a total of thirteen new 230kV breaker terminations.

Pembina Escarpment 1200 MW Transmission Plan 2 involves eight wind farms, with a total length of 134 km of new 230kV radial feeders. In addition, 200 km of new 230kV network transmission is added. The Stanley station would need to be expanded to a seven 230kV breaker ring bus. A new seven breaker

© TransGrid Solutions Inc, 2010

230kV wind collector station is built between Stanley and St. Leon. One new 230kV breaker termination is also required at St. Leon and at Portage, for a total of sixteen new 230kV breaker terminations.

Diversified Development 1200 MW Transmission Plan 1 involves eight wind farms, with a total length of 208 km of new 230kV radial feeders. No new network transmission is added. In addition, 65 km of new network transmission is added. The Stanley station would need to be expanded to a six 230kV breaker ring bus. A new five breaker 230kV wind collector station is built between Stanley and St. Leon. One new 230kV breaker termination is also required at St. Leon as well as at both the Neepawa and Glenboro 230kV stations, for a total of fourteen new 230kV breaker terminations.

Diversified Development 1200 MW Transmission Plan 2 involves eight wind farms, with a total length of 208 km of new 230kV radial feeders. In addition, 200 km of new 230kV network transmission is added. The Stanley station would need to be expanded to a seven 230kV breaker ring bus. A new five breaker 230kV wind collector station is built between Stanley and St. Leon. One new 230kV breaker termination is also required at St. Leon as well as at both the Neepawa and Glenboro 230kV stations, for a total of sixteen new 230kV breaker terminations.

6.3.1. 500kV Option

The radial 500kV option is shown in Figure 6-7. Table 6-4 summarizes this plan.

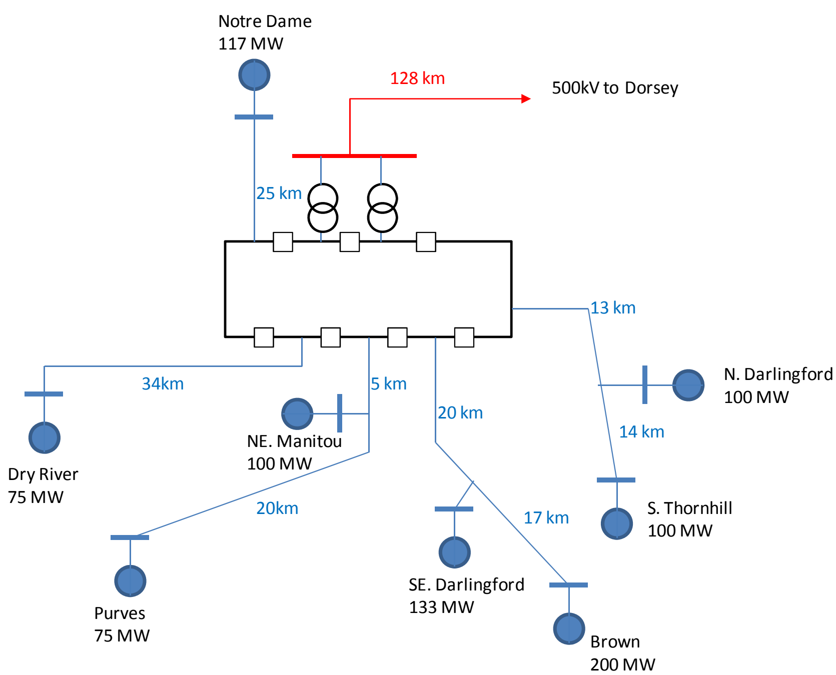


Fig. 6-7. 1200 MW Pembina Escarpment Plan – 500kV Radial Transmission Plan.

© TransGrid Solutions Inc, 2010

Table 6-4. Details of 1200 MW Transmission Plans 1 and 2.

Wind Farm	*Size (MW)*	*Length 230kV Radial Feeders (km)*	*Length New 500kV Network Transmission (km)*	*# New 230kV Breaker Terminations in Ring Bus*	*# New 500kV Breaker Terminations*
1200 MW Pembina Escarpment – 500kV Radial Option					
NE Darlingford	100	13	128	7	3
S Thornhill	100	14			
S Darlingford	100	20			
Brown	200	17			
Notre Dame	100	25			
NE Manitou	100	5			
Dry River	75	34			
Purves	75	20			
Total	900	148	128	7	3

In the 500kV Radial Transmission Plan, only one new seven breaker 230kV wind collector station is built into which all of the eight new wind farms totaling 900 MW are collected. The 230kV collector station is connected to a 500kV line via two 230-500kV step-up transformers. A 128 km 500kV radial transmission line connects the wind collector station to the Dorsey 500kV station. This plan requires 128 km of new 500kV network transmission, and 148 km of new radial 230kV transmission to bring the wind generation to the 230kV collector station. Three 500kV breakers would also be required, one each for the 230-500kV transformers, and one to terminate the new 500kV line at Dorsey.

There are several drawbacks to this particular transmission plan.

1) It is less reliable than the meshed 230kV plans. If the 500kV wind-Dorsey line trips, all of the wind generation is lost.

2) There is also a risk of subsynchronous control interactions if a Type 3 wind turbine is connected radially to a series compensated line [8]. This is not an issue for Type 4 wind turbines however. Some of the vendors are developing control fixes, however these are not trivial. Or the series capacitors could be bypassed.
Depending on where the 500 kV wind line would be terminated into the 500kV Dorsey ring bus, it may be next to a series-compensated line, in which case a single contingency could cause the 500kV wind line to be connected radially to the 500kV series-compensated line. If it were more breaker positions away, then it would take more contingencies to cause this situation. The number of contingencies would dictate the risk involved and would determine what type of mitigation to pursue.

3) Another potentially bad situation that could occur is if the 500kV wind line ever tripped at the same time as the 500kV Dorsey-Forbes line when operating a maximum MH-US export. This could potentially result in the loss of ~900 MW of wind power plus the DC reduction due to loss of the 500kV line, for a total power loss of around 2500 MW, which would exceed the contingency reserves in the MISO pool and would be a reliability concern and a likely show stopper. This would be a NERC Category C event as it would take at least one prior outage to get to this situation.
This contingency will be demonstrated in the transient stability analysis in Section 10.3.

© TransGrid Solutions Inc, 2010

7. Steady State Analysis

Steady state contingency analysis was performed on the selected 230kV and 500kV transmission plans for the 600 MW, 900 MW and 1200 MW wind scenarios. The results were compared with those of the base case.

The 1200 MW 500kV Radial Transmission Plan showed no thermal overload or voltage violation impacts compared to the base case. This makes sense as the new wind generation in this transmission plan is feeding straight into Dorsey, while being offset to the HVDC infeed at Dorsey via reduced northern generation at Keeyask and Conawapa. From a power flow perspective, the base case and the 500kV option with the wind scenario are nearly the same.

The 230kV transmission plans showed the worst case thermal overload impacts during summer peak loading conditions when Brandon generation was off. As was the case in Section 5 for the power transfer limit analysis, there were three existing 230kV network lines that continuously were flagged for thermal loading:

- S53G – St. Leon to Glenboro
- P81C – Portage to Cornwallis
- S60L – Stanley to Letellier

Line S53G from St. Leon to Glenboro is overloaded during some system intact and contingency conditions. Line S53G is a 230kV line comprised of 954 ACRS SC T7 conductor that is currently sagged to 75 deg C. It has a rating of 309.1 MVA , which is limited by the conductor. If the conductor were re-sagged to 100 deg C, the thermal rating of the line would increase to 419.5 MVA, an increase of 35.7%.

Line P81C from Portage to Cornwallis is overloaded following the loss of S53G for certain transmission plans. Line P81C is a 230kV line comprised of 795 ACSR 54/7 conductor that is currently sagged to 75 deg C. It has a rating of 283.6 MVA, which is limited by the conductor. If the conductor were re-sagged to 100 deg C, the thermal rating of the line would increase to 384.4 MVA, an increase of 35.5%.

Line S60L from Stanley to Letellier is overloaded during several contingency conditions. Line S60L has a thermal rating of 318.7 MVA and is currently limited by station equipment. If this station equipment were replaced the next limiting element becomes the line conductor, which is 954 ASCR SD T7 conductor sagged to 100 deg C. The line conductor is rated for 419.5 MVA, which would be an increase of 31.6%.

7.1. 600 MW Wind Scenario

Table 7-1 summarizes the overloads observed for the 600 MW Transmission Plan 1. These overloads were not observed in the base case contingency analysis.

Table 7-1. 600 MW Transmission Plan 1 – Thermal Overloads to be Mitigated.

Overloaded Line	*Contingency*	*Pembina Escarpment*		*Diversified Development*	
		1x500 MH-US	*2x500 MH-US*	*1x500 MH-US*	*2x500 MH-US*
S53G	P81C	107.6	-	-	-
	L20D	110.7*	-	-	-

*102.3% after DC reduction

The only scenario that requires an upgrade is the Pembina Escarpment scenario if there is only one 500kV MH-US tie line. In this case, line S53G would need to be resagged.

The Pembina Escarpment scenario with two 500kV MH-US tie lines and the Diversified Development scenarios both showed no thermal overloads as a result of the wind generation.

© TransGrid Solutions Inc, 2010

7.2. 900 MW Wind Scenario

Table 7-2 summarizes the overloads observed for 900 MW Transmission Plan 1. These overloads were not observed in the base case contingency analysis.

Table 7-2. 900 MW Transmission Plan 1 – Thermal Overloads to be Mitigated.

Overloaded Line	*Contingency*	*Pembina Escarpment*		*Diversified Development*	
		1x500 MH-US	*2x500 MH-US*	*1x500 MH-US*	*2x500 MH-US*
S53G	System intact	105.0	-	-	-
	P81C	124.2	114.9	-	-
	L20D	130.9*	109.9**	-	-
S60L (Let-Stan)	S53G	128.1	121.9	-	-

*121.8% after DC reduction. **107.1% after DC reduction.

The Pembina Escarpment scenario requires line S53G to be resagged and a wavetrap at Stanley to be replaced. This is true whether there are one or two 500kV MH-US tie lines.

The Diversified Development scenario showed no thermal overloads as a result of the wind generation.

Table 7-3 summarizes the overloads observed for 900 MW Transmission Plan 2. These overloads were not observed in the base case contingency analysis.

Table 7-3. 900 MW Transmission Plan 2 – Thermal Overloads to be Mitigated.

Overloaded Line	*Contingency*	*Pembina Escarpment*		*Diversified Development*	
		1x500 MH-US	*2x500 MH-US*	*1x500 MH-US*	*2x500 MH-US*
S53G	System intact	113.3	106.9	-	-
	P81C	132.0	124.7	-	-
	L20D	140.2*	120.9**	-	-
S60L (Let-Stan)	S53G	121.2	110.7	-	-

*131.0% if DC reduction modeled. ** 118.2% after DC reduction.

The Pembina Escarpment scenario requires line S53G to be resagged and a wavetrap at Stanley to be replaced. This is true whether there are one or two 500kV MH-US tie lines.

The Diversified Development scenario showed no thermal overloads as a result of the wind generation.

7.3. 1200 MW Wind Scenario

Table 7-4 summarizes the overloads observed for 1200 MW Transmission Plan 1. These overloads were not observed in the base case contingency analysis.

Table 7-4. 1200 MW Transmission Plan 1 – Thermal Overloads to be Mitigated.

Overloaded Line	*Contingency*	*Pembina Escarpment*		*Diversified Development*	
		1x500 MH-US	*2x500 MH-US*	*1x500 MH-US*	*2x500 MH-US*
S53G	System intact	138.3	129.7	-	-
	P81C	154.5	145.0	106.7	-
	L20D	166.2*	145.1**	121.1***	-
	N54C	151.0	141.8	115.0	104.6
S60L (Let-Stan)	System intact	103.2	101.8	-	-
	S53G	169.6	162.9	127.6	120.8

*156.9% after DC reduction. **142.2% after DC reduction. ***112.4% after DC reduction.

The Pembina Escarpment scenario requires lines S53G and S60L to be reconductored and a wavetrap at Stanley to be replaced. This is true whether there are one or two 500kV MH-US tie lines.

© TransGrid Solutions Inc, 2010

The Diversified Development scenario requires line S53G to be resagged and a wavetrap at Stanley to be replaced. This is true whether there are one or two 500kV MH-US tie lines.

Table 7-5 summarizes the overloads observed for 1200 MW Transmission Plan 2. These overloads were not observed in the base case contingency analysis.

Table 7-5. 1200 MW Transmission Plan 2 – Thermal Overloads to be Mitigated.

Overloaded Line	*Contingency*	*Pembina Escarpment*		*Diversified Development*	
		1x500 MH-US	*2x500 MH-US*	*1x500 MH-US*	*2x500 MH-US*
S53G	System intact	131.4	123.1	-	-
	P81C	148.5	139.3	101.8	-
	L20D	162.2*	140.3**	118.0***	-
	N54C	144.8	135.9	110.2	100.0
S60L (Let-Stan)	S53G	118.2	113.5	-	-

*136.1% after DC reduction. **119.4% after DC reduction. ***96.0% after DC reduction.

The Pembina Escarpment scenario requires line S53G to be reconductored and a wavetrap at Stanley to be replaced. This is true whether there are one or two 500kV MH-US tie lines.

The Diversified Development scenario requires line S53G to be resagged. This is true if there is only one 500kV MH-US tie line. If there are two 500kV MH-US tie lines, the loading on line S53G is at 100% of its thermal rating, therefore it may also require resagging.

7.4. Summary

Table 7-6 summarizes the network upgrades that are required to mitigate thermal overloading caused by the wind generation.

Table 7-6. Summary of Required Network Upgrades for Wind Scenarios.

Transmission Plan	*Pembina Escarpment*		*Diversified Development*	
	1x500 MH-US	*2x500 MH-US*	*1x500 MH-US*	*2x500 MH-US*
600 MW				
Plan 1	Resag S53G	None	None	None
900 MW				
Plan 1	Resag S53G Wavetrap @ Stanley	Resag S53G Wavetrap @ Stanley	None	None
Plan 2	Resag S53G Wavetrap @ Stanley	Resag S53G Wavetrap @ Stanley	None	None
1200 MW				
Plan 1	Reconductor S53G Reconductor S60L Wavetrap @ Stanley	Reconductor S53G Reconductor S60L Wavetrap @ Stanley	Resag S53G Wavetrap @ Stanley	Resag S53G Wavetrap @ Stanley
Plan 2	Reconductor S53G Wavetrap @ Stanley	Reconductor S53G Wavetrap @ Stanley	Resag S53G	None*

*May require S53G resagging as line S53G is at thermal limit (100% loading).

© TransGrid Solutions Inc, 2010

8. Impact to System Losses

System losses are an important factor to consider when designing a transmission plan. During the cost analysis, an estimation of the net present value (NPV) of loss savings or additional cost of losses over a time span (for example 30 years) can be calculated and included as a factor in the final decision making (see Section 13).

The system losses were recorded for the base case and for the selected 230kV transmission plans for the 600 MW, 900 MW and 1200 MW wind scenarios as well as for the 1200 MW 500kV radial transmission plan. The losses are presented for the cases with one and two 500kV MH-US tie lines. In all cases, the wind output is assumed to be at 100%.

The system losses are different between the summer off-peak case with one 500kV tie line and the summer off-peak case with two 500kV tie lines because the generation, MHEX and Manitoba load values are different in both cases. The case with one 500kV line is exporting 2175 MW to the US and has a Manitoba load of 3944 MW, with total HVDC loading of 4460 MW. The case with two 500kV lines is exporting 3275 MW to the US and has a Manitoba load of 3544 MW, with total HVDC loading of 5086 MW. The latter case also has an extra 22 MW at Wuskwatim and 50 MW at Grand Rapids in order to get the MHEX value up to 3275 MW.

All wind generation scenarios were found to result in a decrease in Manitoba system losses compared to the base case. The wind farms are located closer to the Manitoba load centre than the northern hydro generators in the base case, hence the reduction in peak losses. Table 8-1, 8-2 and 8-3 summarize the results for the 600 MW, 900 MW and 1200 MW wind generation scenarios, respectively.

Table 8-1. 600 MW Wind Scenario – Impact to Manitoba Losses.

Loading Conditions	*Manitoba Losses (MW)*					
	One 500 kV MH-US Tie Line			*Two 500kV MH-US Tie Lines*		
	Base Case	*Pembina Plan 1*	*Diversified Plan 1*	*Base Case*	*Pembina Plan 1*	*Diversified Plan 1*
Summer off-peak	461	393	386	537	463	456
Summer peak	600	511	502	605	523	513
Winter peak	608	517	505	603	516	504
Reduction in Manitoba Losses with Wind (MW)						
Summer off-peak	-	68	75	-	74	81
Summer peak	-	89	98	-	82	92
Winter peak	-	91	103	-	87	99

The 600 MW wind scenario results in a loss reduction in the range of 68 - 91 MW for the Pembina Escarpment wind plan, and in the range of 74-103 MW for the Diversified Development wind plan. The highest reduction in losses occurs during winter peak loading.

Table 8-2. 900 MW Wind Scenario – Impact to Manitoba Losses.

Loading Conditions	*Manitoba Losses (MW)*									
	One 500 kV MH-US Tie Line					*Two 500kV MH-US Tie Lines*				
	Base Case	*Pembina*		*Diversified*		*Base Case*	*Pembina*		*Diversified*	
		Plan 1	*Plan 2*	*Plan 1*	*Plan 2*		*Plan 1*	*Plan 2*	*Plan 1*	*Plan 2*
Summer off-peak	461	370	363	357	360	537	439	432	426	428
Summer peak	600	463	472	463	466	605	495	486	477	479
Winter peak	608	483	474	463	464	603	484	475	467	465

© TransGrid Solutions Inc, 2010

Loading Conditions	*Manitoba Losses (MW)*									
	One 500 kV MH-US Tie Line					*Two 500kV MH-US Tie Lines*				
	Base Case	*Pembina*		*Diversified*		*Base Case*	*Pembina*		*Diversified*	
		Plan 1	*Plan 2*	*Plan 1*	*Plan 2*		*Plan 1*	*Plan 2*	*Plan 1*	*Plan 2*
Reduction in Manitoba Losses with Wind (MW)										
Summer off-peak	-	91	98	104	101	-	98	105	111	109
Summer peak	-	137	128	137	134	-	110	119	128	126
Winter peak	-	125	134	145	144	-	119	128	136	138

The 900 MW wind scenario results in a loss reduction in the range of 91-134 MW for the Pembina Escarpment wind plan, and in the range of 104-144 MW for the Diversified Development wind plan. The highest reduction in losses occurs during winter peak loading, with one 500kV MH-US tie line in service.

For the Diversified Development scenario, there is not a significant difference in loss reduction between 900 MW Transmission Plans 1 and 2.

For the Pembina Escarpment scenario, the 900 MW Transmission Plan 2 results in around 10 MW lower losses than 900 MW Transmission Plan 1. This is expected as 900 MW Transmission Plan 2 involves 65 km of new 230 kV network transmission, whereas 900 MW Transmission Plan 1 involves no new 230kV network transmission.

Table 8-3a. 1200 MW Wind Scenario – Impact to Manitoba Losses – 230kV Transmission Plans.

Loading Conditions	*Manitoba Losses (MW)*									
	One 500 kV MH-US Tie Line					*Two 500kV MH-US Tie Lines*				
	Base Case	*Pembina*		*Diversified*		*Base Case*	*Pembina*		*Diversified*	
		Plan 1	*Plan 2*	*Plan 1*	*Plan 2*		*Plan 1*	*Plan 2*	*Plan 1*	*Plan 2*
Summer off-peak	461	354	349	341	339	537	417	412	406	402
Summer peak	600	452	445	438	434	605	469	462	454	449
Winter peak	608	452	446	435	431	603	455	448	436	432
Reduction in Manitoba Losses with Wind (MW)										
Summer off-peak	-	107	112	120	122	-	120	125	131	135
Summer peak	-	148	155	162	166	-	136	143	151	156
Winter peak	-	156	162	173	177	-	148	155	167	171

Table 8-3b. 1200 MW Wind Scenario – Impact to Manitoba Losses – 500kV Transmission Plan.

Loading Conditions	*Manitoba Losses (MW)*			
	One 500 kV MH-US Tie Line		*Two 500kV MH-US Tie Lines*	
	Base Case	*500kV radial*	*Base Case*	*500kV radial*
Summer off-peak	461	371	537	421
Summer peak	600	479	605	486
Winter peak	608	486	603	482
Reduction in Manitoba Losses with Wind (MW)				
Summer off-peak	-	90	-	116
Summer peak	-	121	-	119
Winter peak	-	122	-	121

The 1200 MW wind scenario using the 230kV transmission plans results in a loss reduction in the range of 107-162 MW for the Pembina Escarpment wind plan, and in the range of 120-177 MW for the

© TransGrid Solutions Inc, 2010

Diversified Development wind plan. The highest reduction in losses occurs during winter peak loading, with one 500kV MH-US tie line in service.

1200 MW Transmission Plan 2, with 200 km of new 230 kV network transmission, has slightly lower losses (around 5-8 MW) than 1200 MW Transmission Plan 1 with only 135 km of new 230kV network transmission.

The 1200 MW wind scenario using the radial 500kV transmission plan results in loss reduction in the range of 90-122 MW compared to the base case, which is lower than the loss reduction obtained using the 230kV transmission plans. The radial 500kV transmission plan has around 20-50 MW overall higher system losses than the 230kV transmission plans.

To summarize, as the wind penetration levels in the south increase and the generation in the north decreases, the Manitoba system losses also decrease. The highest reduction in losses was observed in the 1200 MW wind generation plans, as shown in Table 8-4.

Table 8-4. Summary of Wind Scenario Impacts to Manitoba Losses.

# of MH-US 500kV Lines	*Reduction in Manitoba Losses (MW)*						
	600 MW		*900 MW*		*1200 MW*		
	Pembina 230kV	*Diversified 230kV*	*Pembina 230kV*	*Diversified 230kV*	*Pembina 230kV*	*Diversified 230kV*	*Radial 500kV*
One	68-91	75-103	91-134	101-145	107-162	120-177	90-122
Two	74-87	81-99	98-128	109-138	120-155	131-171	116-121

For the 230kV transmission plans being considered, the Diversified Development scenario results in higher loss reduction (approximately 10-15 MW lower system losses) than the Pembina Escarpment scenario.

The 1200 MW radial 500kV transmission plan with the direct feed into Dorsey shows around 20-50 MW higher system losses compared to the 1200 MW 230kV transmission plans.

© TransGrid Solutions Inc, 2010

9. Impact to MH-US Tie Line Power Flows

The MH-US tie line and 500kV Dorsey-Riel power flows were noted for the base case and the 230kV and 500kV transmission plans. Tables 9-1, 9-2 and 9-3 summarize the results.

Table 9-1. 600MW Wind Scenario – MH-US Tie Line Power Flows.

MH-US Tie Line	*MH-US Tie Line Power Flows (MW)*					
	One 500 kV MH-US Tie Line			*Two 500kV MH-US Tie Lines*		
	Base Case	*Pembina Plan 1*	*Diversified Plan 1*	*Base Case*	*Pembina Plan 1*	*Diversified Plan 1*
Summer Off-Peak						
500kV Dorsey-Riel	946	919	928	309	319	331
D602F	1578	1517	1518	1381	1351	1352
New 500kV	-	-	-	1411	1363	1366
R50M	192	186	186	171	168	168
L20D	360	405	386	297	348	329
G82R	45	69	84	21	50	64
Summer Peak						
500kV Dorsey-Riel	879	854	865	334	346	357
D602F	1405	1340	1345	892	863	865
New 500kV	-	-	-	837	786	791
R50M	173	167	164	120	117	117
L20D	308	356	335	177	231	212
G82R	-6	18	34	-82	-54	-39
Winter Peak						
500kV Dorsey-Riel	476	452	463	243	257	269
D602F	768	709	714	556	529	531
New 500kV	-	-	-	351	304	308
R50M	159	153	154	138	135	135
L20D	224	269	250	154	207	188
G82R	-104	-84	-71	-144	-119	-106

Table 9-2. 900MW Wind Scenario – MH-US Tie Line Power Flows.

MH-US Tie Line	*MH-US Tie Line Power Flows (MW)*									
	One 500 kV MH-US Tie Line					*Two 500kV MH-US Tie Lines*				
	Base	*Pembina*		*Diversified*		*Base*	*Pembina*		*Diversified*	
	Case	*Plan1*	*Plan2*	*Plan1*	*Plan2*	*Case*	*Plan1*	*Plan2*	*Plan1*	*Plan2*
Summer Off-Peak										
500kV Dorsey-Riel	946	906	911	918	922	309	325	333	340	344
D602F	1578	1487	1486	1489	1492	1381	1335	1335	1338	1338
New 500kV	-	-	-	-	-	1411	1339	1340	1343	1344
R50M	192	183	183	183	183	171	167	166	167	167
L20D	360	426	416	405	398	297	375	365	353	347
G82R	45	81	90	98	102	21	65	74	80	85
Summer Peak										
500kV Dorsey-Riel	879	841	847	856	859	334	352	362	366	370
D602F	1405	1310	1312	1318	1318	892	848	849	849	851
New 500kV	-	-	-	-	-	837	760	763	764	767
R50M	173	160	160	161	161	120	116	116	116	116
L20D	308	378	368	355	348	177	260	246	237	230
G82R	-6	30	40	48	52	-82	-39	-26	-23	-19
Winter Peak										
500kV Dorsey-Riel	476	438	446	453	457	243	264	272	280	284
D602F	768	676	680	683	684	556	514	514	518	518
New 500kV	-	-	-	-	-	351	278	297	286	286
R50M	159	150	150	151	151	138	133	133	133	133
L20D	224	292	280	270	262	154	236	233	213	205
G82R	-104	-74	-64	-59	-55	-144	-105	-96	-92	-88

© TransGrid Solutions Inc, 2010

Table 9-3. 1200MW Wind Scenario – MH-US Tie Line Power Flows.

MH-US Tie Line	*MH-US Tie Line Power Flows (MW)*									
	One 500 kV MH-US Tie Line					*Two 500kV MH-US Tie Lines*				
	Base	*Pembina*		*Diversified*		*Base*	*Pembina*		*Diversified*	
	Case	*Plan1*	*Plan2*	*Plan1*	*Plan2*	*Case*	*Plan1*	*Plan2*	*Plan1*	*Plan2*
Summer Off-Peak										
500kV Dorsey-Riel	946	904	915	911	922	309	344	354	361	361
D602F	1578	1460	1469	1460	1471	1381	1318	1327	1329	1389
New 500kV	-	-	-	-	-	1411	1314	1328	1328	1330
R50M	192	180	181	180	181	171	165	165	165	167
L20D	360	428	424	415	412	297	384	375	362	363
G82R	45	109	102	119	113	21	96	86	97	97
Summer Peak										
500kV Dorsey-Riel	879	837	845	848	853	334	371	374	380	383
D602F	1405	1280	1291	1288	1295	892	830	838	836	841
New 500kV	-	-	-	-	-	837	733	745	741	850
R50M	173	157	158	158	158	120	114	114	114	115
L20D	308	380	388	366	372	177	267	270	253	256
G82R	-6	58	45	69	58	-82	-8	-23	1	-11
Winter Peak										
500kV Dorsey-Riel	476	437	450	449	458	243	285	295	295	303
D602F	768	649	661	657	664	556	502	507	503	508
New 500kV	-	-	-	-	-	351	258	267	560	270
R50M	159	147	148	148	148	138	132	132	132	132
L20D	224	293	288	281	276	154	242	234	228	221
G82R	-104	-47	-54	-39	-44	-144	-76	-84	-70	-76

All of the wind scenarios using a 230kV transmission plan have similar impacts to the MH-US tie line power flows. Compared to the base case, the south flow on the 500kV line(s) and on R50M is reduced, whereas the south flow on L20D and G82R is increased. This means that in cases where loop flow exists in the base case, such as winter peak and summer peak, the wind generation scenarios using the 230kV transmission plans reduce the MH-US loop flow that is flowing north on G82R, in the range of 50-60 MW.

The Pembina Escarpment scenario and the Diversified Development scenario have very similar impacts to flows on the 500kV line(s) and on R50M. The Diversified Development scenario, because of the wind generation connected at Glenboro, results in even higher increase in south flow on G82R, and less of an increase of south flow on line L20D. This means that the MH-US loop flow is reduced slightly more in the Diversified Development scenario than in the Pembina Escarpment scenario, by approximately 10 MW.

Reducing MH-US loop flow is not necessarily a good thing, depending on the impact to individual tie line power flows. In this case, reducing south flow on the 500kV line(s) is a good thing, however increasing south flow on line L20D is not good. Loading on line L20D, particularly under low NDEX conditions, is known to be an issue. A previous study [1] found that L20D upgrades were required based on summer export conditions when NDEX is low. The worst contingency was a Category C disturbance in the US at Rugby (loss of Rugby bank and the Rugby-Balta line). This overload will be made worse depending on the status of the Rugby wind farm and the G904 (G82R tap) wind farm, both of which were assumed to trip of for this contingency in that study. This particular contingency was not addressed in this Exploratory Study, nor were the low NDEX conditions.

A slightly bigger increase on L20D south flow was observed with the wind generation if the second 500kV tie line was in service. With two 500kV tie lines, L20D south flow increased in the range of 65-90 MW with the 1200MW wind generation scenarios, as opposed to 52-80 MW with only one 500kV tie line. However, the steady state south flow on L20D is around 60-130 MW lower in the case with the second 500kV tie line, therefore the slightly larger increase in L20D south flow observed with the wind generation if the second 500kV tie line is present is not necessarily an issue.

The approximate percentages of wind plant output flowing south on L20D ranged from 4.7%-9.3% for the case with on 500kV tie line, and from 5.8%-10.4% with two 500kV tie lines.

© TransGrid Solutions Inc, 2010

The power flow cases used in this study were set to intermediate NDEX levels, ranging from 1029 MW to 1492 MW. Further power flow analysis at more stressed NDEX conditions would be required to determine if L20D upgrades would be needed based on the increased L20D south flow associated with the wind generation scenarios. It is anticipated that with the increases observed in this study that L20D may indeed require upgrading in some of the wind generation scenarios.

The radial 500kV transmission plan has no significant impact on the MH-US tie line power flows. This makes sense as the new wind generation in this transmission plan is feeding directly into Dorsey, while being offset to the HVDC infeed at Dorsey via reduced northern generation at Keeyask and Conawapa. From a power flow perspective, the base case and the 500kV option with the wind scenario are nearly the same.

© TransGrid Solutions Inc, 2010

10. Transient Stability Analysis

The transient stability analysis focused on Type 3 wind generators, which is the doubly fed induction generator (DFIG) type. Sensitivity analysis was performed to see the impact of replacing the Type 3 wind generators with Type 4 wind generators, which is the full converter type.

The addition of up to 1200 MW of wind generation in southern Manitoba, being offset by future generation expansions in the northern collector system, was not observed to have a significant impact on the performance of the Manitoba system. The system at the POIs appears to be strong enough to allow the wind generators to perform adequately. The interconnection of the new wind generation and the associated transmission plans were analyzed to ensure compliance with the Manitoba grid code [4]. Specifically, the worst case system underfrequency event and the worst case system overvoltage events were simulated to see the impact of the wind generation on the overall performance of the system. Local normal-clearing three phase line faults near the wind plants were also analyzed to ensure the adequacy of the transmission plans and to screen for any poorly damped oscillations originating from the wind plants after fault recovery.

10.1. Overvoltage

The system overvoltage event was simulated by performing a double bipole block. In other words, two of the Manitoba HVDC bipoles were blocked simultaneously. Figure 10-1 shows a sample of the system voltage at the 230kV St. Leon bus for the base case and the 600 MW, 900 MW and 1200 MW wind scenarios corresponding to the selected 230kV transmission plans and the radial 500kV transmission plan.

© TransGrid Solutions Inc, 2010

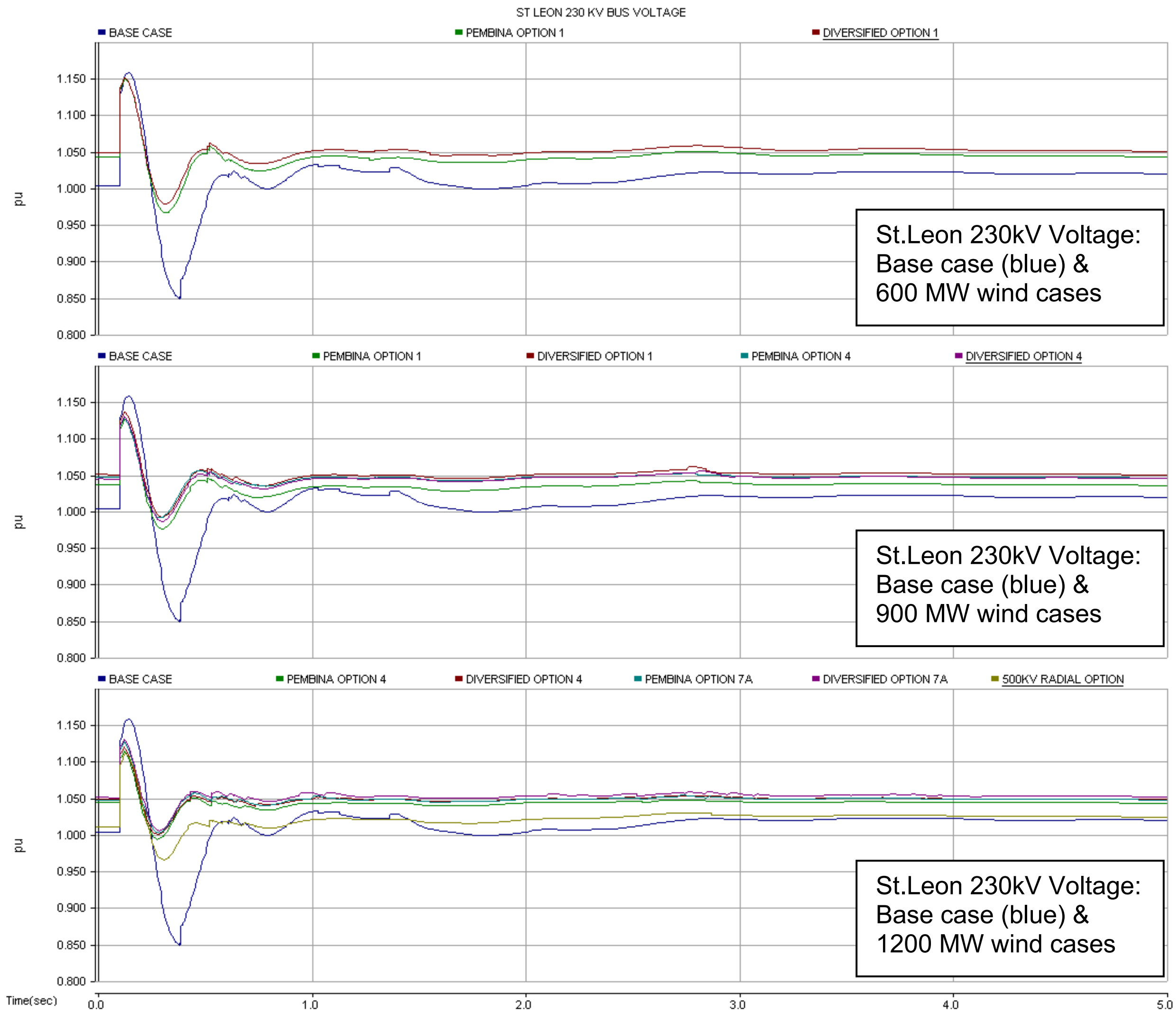


Fig. 10-1. TOV at St.Leon 230kV after double bipole block.

Figure 10-1 shows that the TOV is highest in the base case (blue curve). The wind scenarios reduce the system overvoltage near the POI. The overvoltage is within the ride-through capability of the wind generators. The improvement in voltage performance is a significant advantage for the wind scenarios. Not only does the transient overvoltage performance improve in the wind scenario, so does the transient undervoltage. Given the load growth, the base case may eventually require some dynamic reactive support to correct the voltage drop.

The highest overvoltages observed at the wind generator terminals did not in fact come from the double bipole block. A three-phase fault at the wind POI resulted in the worst case overvoltages at the wind generator terminals after fault clearing as shown in Figure 10-2 for the various wind scenarios and transmission plans. The overvoltages were limited to 1.2 pu by the wind generator controls, which is within the ride-through capability of the wind generators.

© TransGrid Solutions Inc, 2010

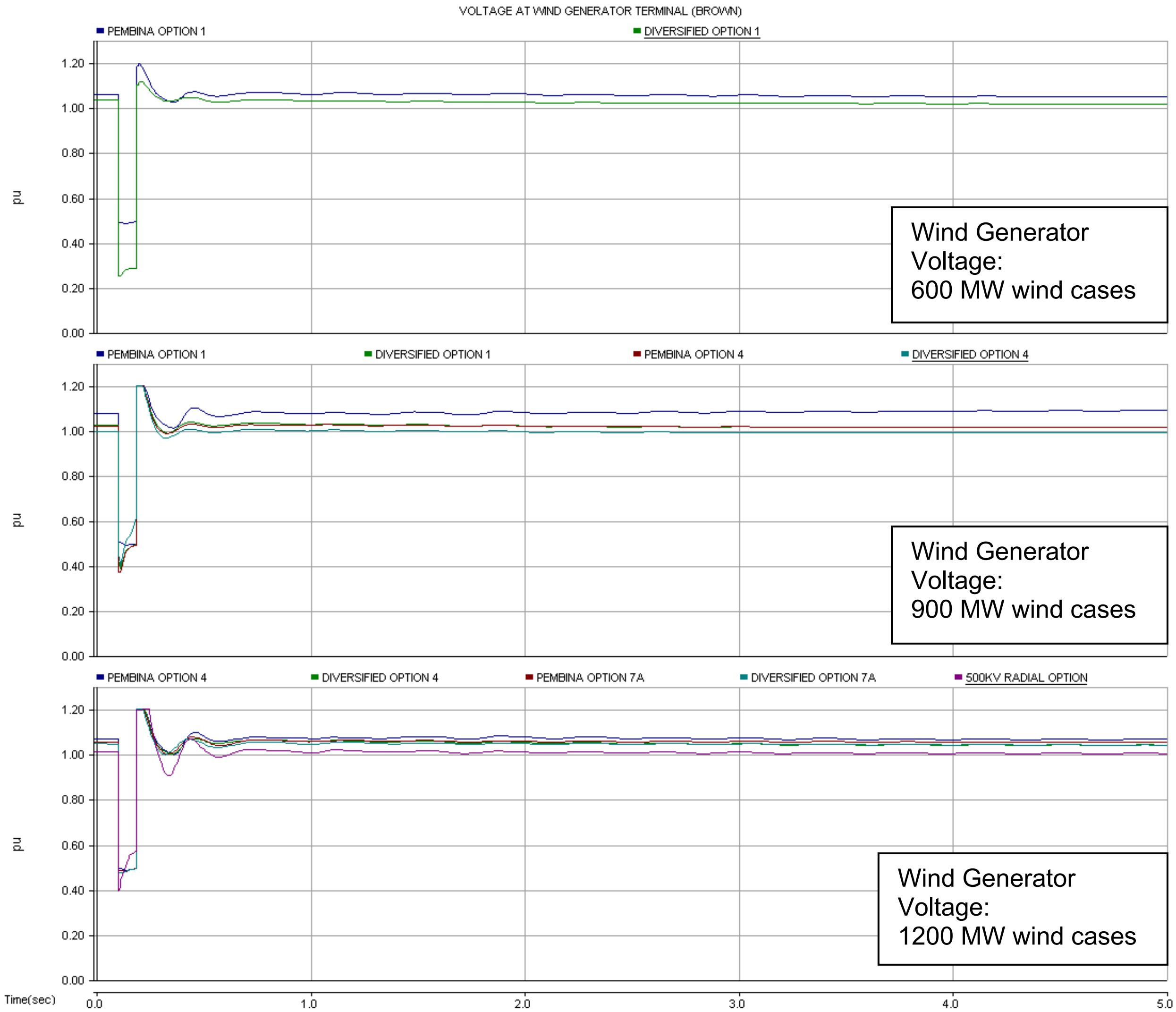


Fig. 10-2. Overvoltage at wind generator terminals after fault at POI.

10.2. Underfrequency

The system underfrequency event was simulated by applying a three phase fault in the northern collector system.

A three-phase fault in the northern collector system effectively results in loss of a significant portion of Manitoba's HVDC power infeed in the south. The northern collector system is isolated from the rest of the grid, connected only to the rectifier ends of the three HVDC bipoles. A three-phase fault in this system can result in a temporary loss of a large portion of the hydro generation in the collector system, and therefore loss of the power on the HVDC bipoles. This leads to a temporary underfrequency in the southern system.

Figure 10-3 shows the system frequency and a sample power output of one of the wind plants for the northern collector system fault.

© TransGrid Solutions Inc, 2010

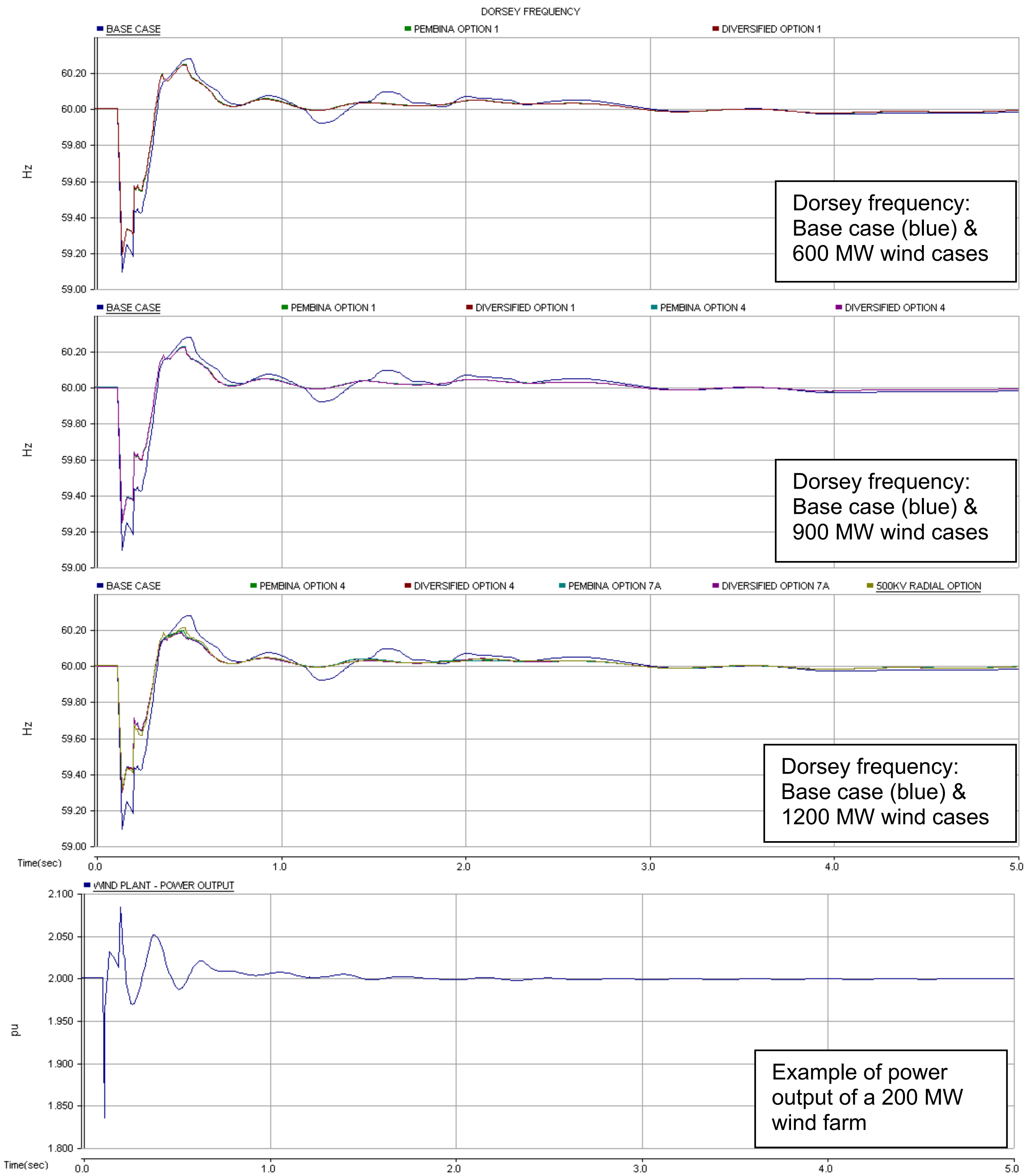


Fig. 10-3. Northern collector system fault. System frequency and wind plant power output.

Figure 10-3 shows that the wind scenarios actually improve the system underfrequency for this fault. This is because the wind generation is replacing hydro generation in the northern collector system, thus there is lower loading on the HVDC bipoles in the wind scenarios. A three-phase fault in the northern collector system therefore results in loss of less power in the wind scenarios, leading to a lesser underfrequency; the more wind generation that is connected in the south, the lesser the underfrequency. If the wind generation were to replace southern system generation or generation in the neighboring US while keeping the HVDC bipoles fully loaded, then the underfrequency was found to be virtually the same for the base case and the wind generation scenarios.

© TransGrid Solutions Inc, 2010

The northern collector system fault results in an underfrequency down to around 59.2 Hz. This is within the underfrequency ride-through capability of the wind generators and also did not trigger the first underfrequency load shed point in the Manitoba system. Advances in wind turbine controls, may make it feasible to improve the underfrequency performance [9].

The wind inertia controls in the Type 3 wind generator models were enabled to see if the underfrequency could be improved. Using the recommended settings in the GE wind model manual [1] did not provide a fast enough response to modify the frequency response of the system. Further work would be required to determine if modified settings for the wind inertia controls are feasible and if these modified settings would be of benefit to the system frequency response to underfrequency events.

10.3. 500kV Transmission Plan: Loss of Wind and 500kV Tie Line

One concern for the 500kV radial transmission plan is the potential to lose the 500kV radial wind line as well as the 500kV MH-US tie line. When operating at maximum MH-US export, this could potentially result in the loss of ~900 MW of wind power plus the DC reduction due to loss of the 500kV line, for a total power loss of around 2500 MW, which would exceed the contingency reserves in the MISO pool and would be a reliability concern and a likely show stopper. This would be a NERC Category C event as it would take at least one prior outage to get to this situation.

The worst case was the summer off-peak case at maximum MHEX of 2175 MW with only one 500kV tie line in service. The results showed that the system response was stable. The frequency dipped down to around 59.65 Hz, as shown in Figure 10-4.

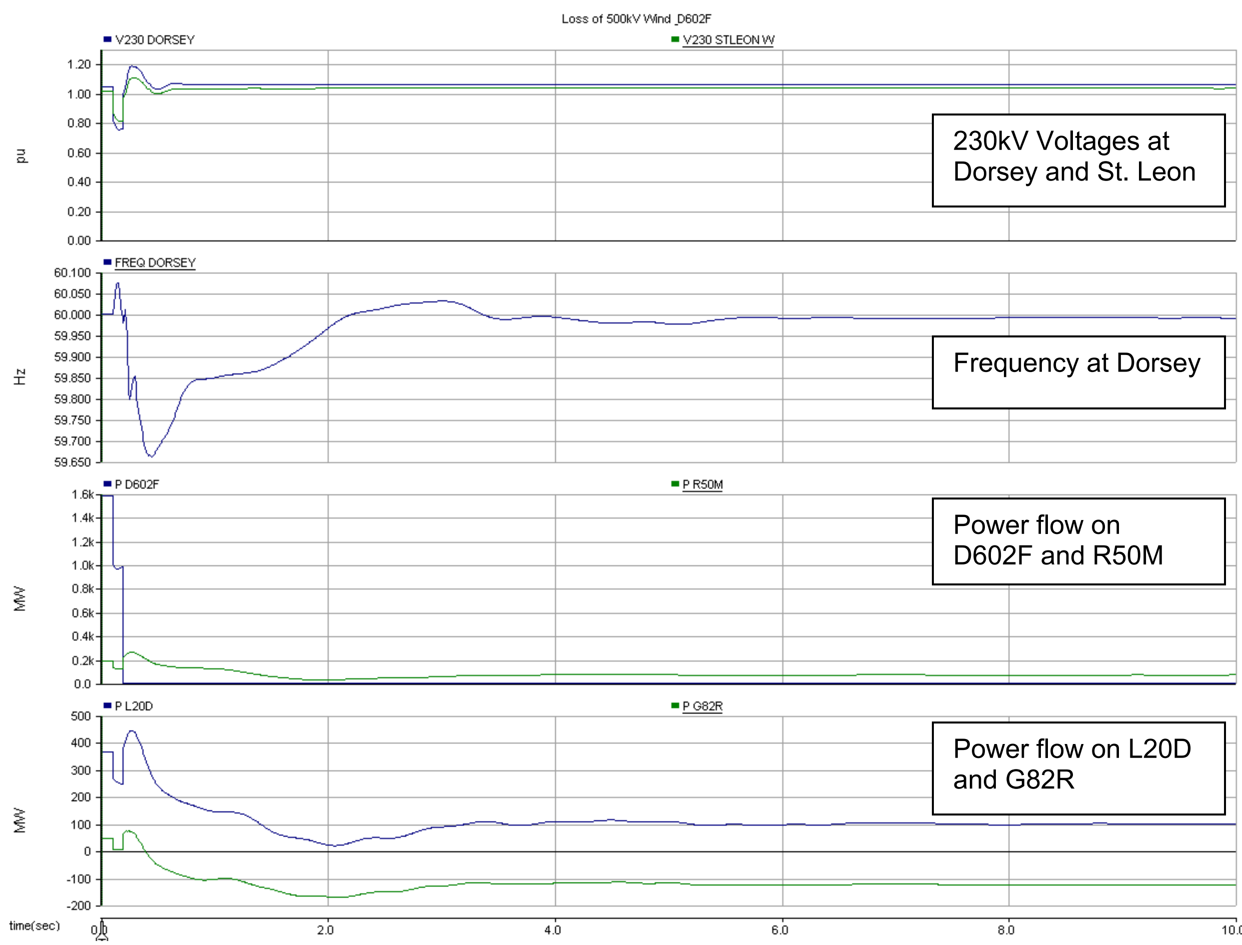


Figure 10-4. Loss of 500kV Wind Line and D602F.

© TransGrid Solutions Inc, 2010

10.4. Local Three-Phase Faults

Various three-phase line faults near the wind plants were analyzed to assess the adequacy of the various transmission plans and wind generation scenarios, and to ensure sufficient outlet transmission was still available in case of a fault on an outlet line. There were no faults that resulted in unacceptable system performance. The only issue noted was poorly damped local torsional oscillations observed in the GE 3.6 MW wind turbines when modeled as a 2-mass system, as further explained in Section 10.4.

Various system configurations were tested, such as fewer synchronous condensers at the HVDC inverter stations, diverting the wind power to the US or to southern system generation in Manitoba instead of to the HVDC power, in an attempt to create a weaker system near the wind plants, and hence a lower short circuit ratio (SCR). In all cases the SCR remained around 2.8 or higher, and no major issues were observed.

One thing to note is that a future detailed interconnection study would need to look at the impact of slow-clearing breaker fail scenarios. This study only investigated normal-clearing three-phase faults.

10.5. Comparison of Type 3 and Type 4

In terms of comparing the performance of the Type 3 and Type 4 wind plants, there was not a significant impact to the performance of the grid. Figure 10-4 provides an example of the wind power output and bus voltage at the POI for both types. Both types of wind plants were observed to have similar power recovery rates after faults. The Type 4 wind plants had slightly faster voltage control. If the Type 3 wind generators were modeled using a 2-mass rotor model that represented the turbine and generator separately (which according to the model documentation is not valid for the Type 4 wind generators [1]), some small but poorly damped local torsional oscillations could be observed in the Type 3 power outputs at certain wind plants. These oscillations were observed with the 3.6 MW turbines and had a frequency around 2.6 Hz and a damping ratio of approximately 2%, which is below the 5% damping criteria. They are fairly well damped beyond 5 seconds. No such oscillations were present in the Type 4 power outputs. The oscillations in the Type 3 wind generators would require mitigation to meet the 5% damping criteria.

The poorly damped oscillations observed in the 3.6 MW Type 3 wind farms are a local torsional mode, as mentioned in the PSSE GE model manual [1]. The oscillations can be observed when separate masses for the turbine and generator are modeled. Because the mode is local to the wind farm, mitigation local to the wind farm would make sense. It may be possible to fine tune controllers in the wind turbine or possibly add a local damping controller to the wind turbine in order to improve the damping. It is possible that a more detailed wind plant model would be required to analyze the oscillations in more detail and to determine mitigation. It would be recommended to approach the manufacturer (GE) to obtain their expert opinion on mitigation of the poorly damped oscillations.

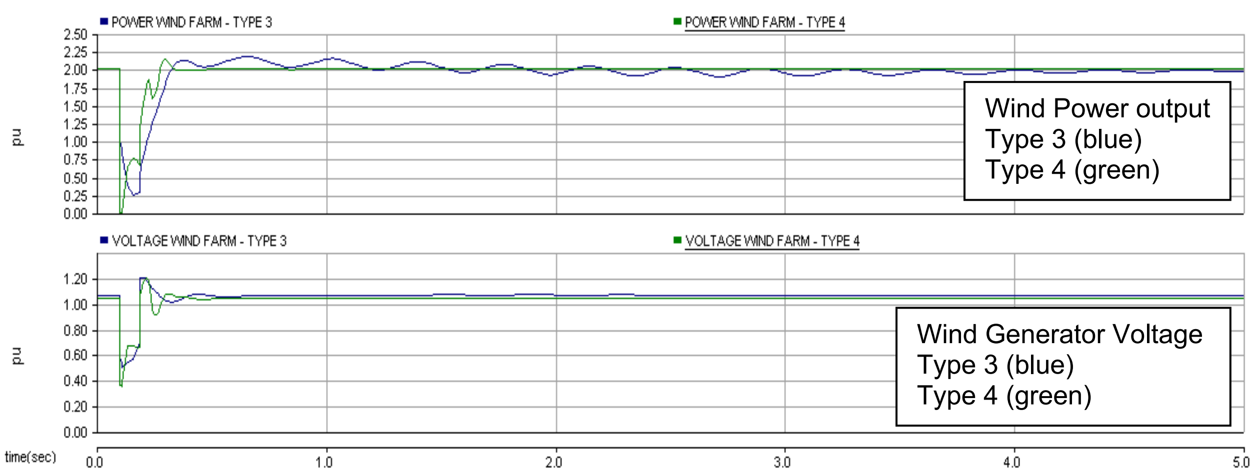


Fig. 10-4. Comparison of type 3 and 4 wind turbine performance.

© TransGrid Solutions Inc, 2010

10.6. Summary

To summarize, the selected 230kV and 500kV transmission plans were assessed for the interconnection of 600 MW, 900 MW and 1200 MW of wind generation in southwestern Manitoba. The SCRs at the POIs for each transmission plan were 3 or greater. There were no adverse impacts observed to system stability issues in terms of voltages or frequency excursions. In fact, off-loading the HVDC bipoles by replacing hydro generation in the north with wind generation in the south was shown to improve the worst case system underfrequency. Type 3 and Type 4 wind generators showed relatively similar performance, although when modeled using a 2-mass rotor representation, the Type 3 wind generators had potential to experience small but poorly damped local torsional oscillations, which took up to five seconds to damp out in the worst cases. These oscillations would require mitigation to meet the 5% damping criteria. Since the oscillations are local to the wind plant, local mitigation in terms of fine tuning wind plant controllers or adding a damping controller may be a solution. It would be recommended to contact GE with regards to these poorly damped oscillations.

There was no significant difference in the system performance when comparing the various 230kV transmission plans and the radial 500kV transmission plan. All plans showed similar system performance.

Please note that the stability analysis performed in this study is not intended to be a comprehensive stability study. It is only a high level analysis to show feasibility and to determine possible transmission plans to connect the wind generation. Further studies using more power flow cases (including import scenarios) and more faults (including slow-clearing breaker fail scenarios), as well as more focus on voltage control settings and tap changer ranges/settings associated with wind farm collector systems would be warranted.

© TransGrid Solutions Inc, 2010

11. Short Circuit Analysis

The short circuit ratios (SCR) were calculated at all of the POI buses for each of the wind scenarios and corresponding transmission plans, as summarized in Table 11-1. Previous work has determined that too low an SCR is an issue for the stability of Type 1[2] wind turbines [10].

Table 11-1. Short Circuit Ratios at Wind POIs.

Transmission Plan	*Bus*	*Total Wind Generation at Bus (MW)*	*System intact*		*ALL SYNCS OUT*	
			Short Circuit Level (MVA)	SCR	Short Circuit Level (MVA)	SCR
600 MW Pembina Escarpment						
Plan 1	Stanley	300	2167	7.2	2016	6.7
600 MW Diversified Development						
Plan 1	Stanley	100	2096	21.0	1946	19.5
	Killarney	100	768	7.7	759	7.6
	Minnedosa	100	910	9.1	880	8.8
900 MW Pembina Escarpment						
Plan 1	Stanley	600	2471	4.1	2314	3.9
Plan 2	Stanley/Wind	600	2715	4.5	2515	4.2
900 MW Diversified Development						
Plan 1	Stanley	350	2300	6.6	2146	6.1
	Killarney	100	771	7.7	761	7.6
	Minnedosa	150	911	6.1	880	5.9
Plan 2	Stanley/Wind	350	2059	8.7	1948	5.6
	Killarney	100	774	7.7	765	7.7
	Minnedosa	150	911	6.1	881	5.9
1200 MW Pembina Escarpment						
Plan 1	Stanley/Wind	900	2782	3.1	2590	2.9
Plan 2	Stanley/Wind	900	2947	3.3	2678	3.0
1200 MW Diversified Development						
Plan 1	Stanley/Wind	650	2239	3.4	2110	3.2
	Killarney	100	777	7.8	768	7.7
	Minnedosa	150	912	6.1	882	5.9
Plan 2	Stanley/Wind	650	2742	4.2	2495	3.8
	Killarney	100	781	7.8	769	7.7
	Minnedosa	150	912	6.1	882	5.9
1200 MW Pembina Escarpment						
500kV Radial	Wind	900	2939	3.3	2449	2.7

The short circuit ratios (SCR) at the wind plant POIs were calculated to be 3 or greater in all of the transmission plans during system intact conditions (with one synchronous condenser out of service at Dorsey and one at Riel). The calculations were performed using the summer off-peak power flow cases.

To test a weaker system, all synchronous condensers were removed from service at Dorsey and Riel. Even then, the SCRs at the wind plant POIs remained above 3, with the exception of the 1200 MW Pembina Escarpment 230kV Transmission Plan 2 at 2.9 and the Radial 500kV Transmission Plan at 2.7.

In terms of impacts to existing short circuit levels, the base case short circuit currents at buses with voltage levels 110kV and above were compared to 1200 MW Transmission Plan 2 as this plan adds the most new wind generation and transmission, therefore will impact the existing base case levels the most. There were three 230kV buses with increases greater than 5% as listed in Table 11-2.

[2] Type 1 through Type 4 wind turbines are described in [11].

© TransGrid Solutions Inc, 2010

Table 11-2. Impact of 1200 MW Wind Scenario to Base Case Short Circuit Levels.

Bus	*Base Case (kA)*	*Pembina Escarpment Option 7a (kA)*	*Impact (%)*	*Diversified Development Option 7a (kA)*	*Impact (%)*
Stanley	5.47	7.99	46.1	7.50	37.3
St. Leon	7.16	9.75	36.3	9.16	27.9
Portage	9.81	10.75	9.6	10.74	9.5

© TransGrid Solutions Inc, 2010

12. No Wind Scenario

An analysis was conducted assuming all wind generation was off line in the winter peak, summer peak and summer off peak cases. Keeyask was assumed to be offline and the additional future load was served by Conawapa and thermal generation at Brandon and Selkirk.

The objective was to determine if there are any major network issues with supplying the future load via thermal units at Brandon and Selkirk.

The case summaries comparing the base case and no wind cases are provided in Table 12-1.

With the retirement of Brandon unit 5 (105.9 MW) in 2018, an additional 88.6 MW would be needed at Brandon to maintain the same MHEX levels and serve the same Manitoba load levels as the base cases. This is in addition to the two 140 MW units at Brandon and the two 70 MW units at Selkirk.

Table 12-1. Case summaries: Base Case and No Wind cases.

Case	*MH DC Loading (MW)*			*MHEX (MW)*	*Manitoba Generation (MW)*						
	BP1	*BP2*	*BP3*		*WPG River*	*Grand Rapids*	*Brandon*	*Selkirk*	*Conawapa*	*Keeyask*	*Dorsey MVAR Cushion*
Summer Off-Peak, One 500kV MH-US Tie Line											
Base Case	1414	1526	1522	2175	653	430	0	0	1100	533	931.5
No Wind	1260	1372	1366	2176	653	430	368.6	70	1100	0	1337
Summer Off-Peak, Two 500kV MH-US Tie Lines											
Base Case	1612	1740	1734	3281	653	480	0	0	1284	623	842.9
No Wind	1438	1566	1560	3284	653	480	368.6	140	1284	0	1271
Summer Peak, One 500kV MH-US Tie Line											
Base Case	1610	1780	1778	1881	653	480	0	0	1300	630	388
No Wind	1440	1600	1600	1881	653	480	354.6	140	1300	0	911
Summer Peak, Two 500kV MH-US Tie Lines											
Base Case	1636	1766	1762	1945	653	480	0	0	1300	630	534
No Wind	1460	1590	1586	1944	653	480	354.6	140	1300	0	1057
Winter Peak, One 500kV MH-US Tie Line											
Base Case	1636	1763	1760	1042	653	480	0	0	1300	631	889.5
No Wind	1460	1590	1584	1047	653	480	344.6	140	1300	0	1396
Winter Peak, Two 500kV MH-US Tie Lines											
Base Case	1636	1764	1760	1053	653	480	0	0	1300	631	829.3
No Wind	1460	1588	1584	1055	653	480	348.6	140	1300	0	1412

12.1. Steady state contingency analysis

Steady state contingency analysis did not reveal any new thermal overloads or voltage violations or any adverse impacts to overloads that already exist in the base 2030 case.

12.2. Impact to System Losses

The losses were recorded for the base cases and the no wind cases. The results are summarized in Table 12-2.

© TransGrid Solutions Inc, 2010

Table 12-2. No Wind Scenario: Impact to System Losses.

Loading Conditions	*Manitoba Losses (MW)*			
	One 500 kV MH-US Tie Line		*Two 500kV MH-US Tie Lines*	
	Base Case	*No Wind*	*Base Case*	*No Wind*
Summer off-peak	461	364	537	423
Summer peak	600	464	605	470
Winter peak	608	463	603	459
Reduction in Manitoba Losses with southern thermal generation (MW)				
Summer off-peak	-	97	-	114
Summer peak	-	136	-	135
Winter peak	-	145	-	144

Similar to the wind scenarios, increasing Brandon and Selkirk generation and decreasing northern hydro generation results in a reduction in Manitoba losses, as the thermal generation is located in the south of the province which is closer to the Manitoba load center. The no wind scenario results in a loss reduction in the range of 97-144 MW compared to the base case. The highest reduction in losses occurs during winter peak loading.

12.3. Impact to MH-US Tie Line Flows

The MH-US tie line power flows were recorded for the base cases and the no wind cases. The results are summarized in Table 12-3.

Table 12-3. No Wind Scenario: Impact to MH-US Tie Line Flows.

MH-US Tie Line	*MH-US Tie Line Power Flows (MW)*			
	One 500 kV MH-US Tie Line		*Two 500kV MH-US Tie Lines*	
	Base Case	*No Wind*	*Base Case*	*No Wind*
Summer Off-Peak				
500kV Dorsey-Riel	946	949	309	332
D602F	1578	1552	1381	1367
New 500kV	-	-	1411	1390
R50M	192	185	171	170
L20D	360	359	297	300
G82R	45	81	21	57
Summer Peak				
500kV Dorsey-Riel	879	878	334	355
D602F	1405	1375	892	879
New 500kV	-	-	837	814
R50M	173	170	120	119
L20D	308	307	177	180
G82R	-6	29	-82	-48
Winter Peak				
500kV Dorsey-Riel	476	481	243	268
D602F	768	745	556	545
New 500kV	-	-	351	333
R50M	159	157	138	136
L20D	224	224	154	157
G82R	-104	-78	-144	-117

The no wind scenario results in a lesser south flow on the 500kV line(s) and on line R50M, and higher south flow on line G82R. Line L20D is not significantly affected. This means that in cases where loop flow exists in the base case, such as winter peak and summer peak, the no wind scenario reduces or eliminates the MH-US loop flow that is flowing north on G82R, in the range of 25-35 MW.

© TransGrid Solutions Inc, 2010

12.4. Short Circuit Analysis

Short circuit analysis revealed a list of 230kV and 110kV buses with increased short circuit levels in the no wind cases. Those increased by 5% or more are summarized in Table 12-4. No fault levels above 40kA were observed, with the exception of the Dorsey 230kV buses.

Table 12-4. Impact of No Wind Scenario on Base Case Short Circuit Levels.

			WIPK - One 500kV MH-US Line			WIPK - Two 500kV MH-US Lines		
Bus Description			Base Case	No Wind	Impact	Base Case	No Wind	Impact
No	Name	kV	kA	kA	(%)	kA	kA	(%)
667032	DORSY2M4	230	49.7	52.7	6.1	55.5	58.6	5.7
667034	DORSEYM4	230	51.5	54.7	6.4	57.8	61.2	5.9
667052	GLENBOR4	230	5.9	6.4	8.9	5.9	6.4	8.7
667053	PORTSOU4	230	8.5	9.1	7.5	8.7	9.3	7.2
667067	RESTON 4	230	4.1	4.3	6.2	4.1	4.3	6.1
667068	SOURIPL4	230	4.1	4.7	15.2	4.1	4.7	15.0
667069	SOURSTP4	230	4.9	5.8	19.0	4.9	5.8	18.8
667070	CORNWLS4	230	7.2	10.4	43.8	7.3	10.5	43.4
667071	NEEPAWA4	230	4.2	4.7	12.4	4.2	4.8	12.2
668015	MR11 T 7	110	4.4	4.8	10.3	4.4	4.8	10.2
668016	RAPDCTY7	110	4.4	5.0	12.6	4.4	5.0	12.5
668017	BRANE 7	110	11.2	19.0	69.5	11.3	19.0	69.0
668018	HIGHLND7	110	7.9	11.1	40.9	7.9	11.1	40.5
668019	FORTIER7	110	7.1	9.6	35.5	7.1	9.7	35.2
668020	CROCUSP7	110	8.4	12.1	44.7	8.4	12.2	44.3
668021	BD52-TP7	110	9.6	14.9	55.0	9.7	14.9	54.5
668022	BRANDON7	110	11.7	20.6	75.9	11.8	20.7	75.3
668023	BE1 TP 7	110	11.7	20.6	75.9	11.8	20.7	75.3
668024	SIMPB2 7	110	9.8	15.2	56.1	9.8	15.3	55.7
668025	SIMPB1 7	110	9.8	15.2	56.1	9.8	15.3	55.7
668026	BK41-TP7	110	9.5	14.7	54.1	9.6	14.7	53.6
668027	MAPLELF7	110	8.2	11.8	43.6	8.3	11.8	43.2
668028	CANEXUS7	110	8.3	12.0	44.3	8.4	12.0	43.9
668029	NEPWA 7	110	3.7	4.1	9.2	3.7	4.1	9.1
668030	MINDOS 7	110	3.9	4.3	9.2	3.9	4.3	9.1
668040	PARKDAL7	110	19.9	21.6	8.6	20.2	21.9	8.3
668041	CARBB2 7	110	2.5	2.7	6.2	2.5	2.7	6.1
668045	CARBRYN7	110	2.5	2.7	6.3	2.5	2.7	6.2
668065	SELKIRK7	110	12.9	16.5	28.2	13.0	16.6	27.9
668066	MERCYST7	110	11.0	12.9	17.2	11.1	12.9	16.9
668067	SELKMLL7	110	9.4	10.8	14.4	9.5	10.9	14.2
668068	PRAXAIR7	110	9.3	10.6	14.1	9.3	10.6	13.9
668069	ESTSELK7	110	12.3	15.4	25.6	12.4	15.5	25.3
668070	CORNW1 7	110	11.5	19.9	72.5	11.6	19.9	71.9
668071	CORNW3 7	110	11.7	20.2	72.2	11.8	20.3	71.6
668072	CORNW427	110	11.5	19.9	72.5	11.6	19.9	71.9
668073	GARSON7	110	9.2	10.4	13.8	9.2	10.5	13.5
668074	OAKBANK7	110	7.7	8.1	6.1	7.7	8.2	5.9

© TransGrid Solutions Inc, 2010

12.5. Summary

The No Wind scenario does not appear to have any major network issues with supplying the future load via thermal units at Brandon and Selkirk.

No new transmission or network upgrades were identified in this analysis.

With the retirement of Brandon unit 5 (105.9 MW) in 2018, the analysis found that an additional 88.6 MW would be needed at Brandon to maintain the same MHEX levels and serve the same Manitoba load levels as the base cases. This is in addition to the two 140 MW units at Brandon and the two 70 MW units at Selkirk. Although no new transmission or network upgrades are needed, there would be some termination costs associated with this new thermal generation. These termination costs are not considered in this report.

© TransGrid Solutions Inc, 2010

13. Cost Estimates

Planning level cost estimates were calculated for each of the transmission plans that were studied in detail in this report. The cost estimates are broken down into four categories:

- New network transmission
- New stations/breaker terminations
- New 230kV wind direct connect transmission lines
- Network upgrades

Following these cost estimates, the value of system loss savings achieved with the wind scenarios and the no wind scenario is also calculated for each of the transmission plans.

13.1. Unit Cost Estimates

The transmission line unit cost estimates are based on recently updated planning level line costs. The rest of the unit cost estimates were based on those used in a previous study, which were based on 2006 dollars. An escalation rate of 2% per year was assumed when calculating the unit cost estimates for 2010, as given in Table 13-1.

Table 13-1. Planning Level Unit Cost Estimates.

Equipment	*Cost Estimates*	
	Year 2006	*Year 2010*
New Facilities		
230 kV Transmission Line < 10 km	-	$370,000 /km
230 kV Transmission Line > 10 km	-	$500,000 /km
500 kV Transmission Line	-	$1,250,000 /km
230 kV breaker termination	$3.5 million	$3.79 million
500 kV breaker termination	$6.0 million	$6.49 million
230-500 kV 1200 MVA transformer*	$36.0 million	$38.97 million
Network Upgrades		
Reconductor 230 kV with same size ACSS**	$80,000 /km	$86,595 /km
Retension 230 kV line	$15,000 /km	$16,236 /km
Station riser upgrades	$100,000 /site	$108,243 /site
CT replacement	$200,000 /site	$216,486 /site
Wavetrap replacement	$100,000 /site	$108,243 /site

* 3 single-phase windings

**the conductor costs range from $30,000/km for 266.8 ACSS to $60,000/km for 1272 ACSS assuming more than 10km. ACSR conductor is slightly cheaper for the same conductor size. The structural modifications are in the range of $40,000/km, more for ACSR than ACSS. The costs are higher for less than 10km due to fixed mobilization/demobilization and project management costs. Therefore the following is assumed: $30,000-$100,000/km if > 10km; add 35% if < 10km.

13.2. Transmission Plans

The cost estimate for the 600 MW Pembina Escarpment and Diversified Development wind generation scenarios for Transmission Plan 1 is provided in Table 13-2.

© TransGrid Solutions Inc, 2010

Table 13-2. Cost Estimate – 600MW Scenarios, Transmission Plan 1.

New Facilities & Network Upgrades		***600 MW Transmission Plan 1***			
		Pembina Escarpment		***Diversified Development***	
New Network Transmission					
none			$0		$0
	Subtotal		*$0*		*$0*
New Network Stations/Breakers					
Expand Stanley station	breakers	5	$18,942,563	4	$15,154,050
Expand Glenboro station				1	$3,788,513
Expand Neepawa station				1	$3,788,513
	Subtotal		*$18,942,563*		*$22,731,075*
New 230kV Wind Connection Lines					
Radial 230kV Feeders	km	20	$10,000,000	120	$60,000,000
	Subtotal		*$10,000,000*		*$60,000,000*
Network Upgrades					
Resag line S53G*	km	51	$832,932		$0
	Subtotal		*$832,932*		*$0*
	Total		**$29,775,494**		**$82,731,075**

*not needed if there are two 500kV MH-US lines

The cost estimate for the 600 MW Pembina Escarpment plan is $29.78 million and for the 600 MW Diversified Development plan is $82.73 million. The Diversified Development plan costs more mainly due to the additional 230kV wind connection transmission lines, in particular the long direct connect lines from the Killarney and Minnedosa wind farms to Glenboro and Neepawa, respectively, in the Diversified Development plan.

The cost estimates for the 900 MW Pembina Escarpment and Diversified Development wind generation scenarios for Transmission Plans 1 and 2 are provided in Tables 13-3 and 13-4, respectively.

© TransGrid Solutions Inc, 2010

Table 13-3. Cost Estimate – 900MW Scenarios, Transmission Plan 1.

New Facilities & Network Upgrades		*900 MW Transmission Plan 1*			
		Pembina Escarpment		*Diversified Development*	
New Network Transmission					
none			$0		$0
	Subtotal		*$0*		*$0*
New Network Stations/Breakers					
Expand Stanley station	breakers	6	$22,731,075	6	$22,731,075
Expand Glenboro station				1	$3,788,513
Expand Neepawa station				1	$3,788,513
	Subtotal		*$22,731,075*		*$30,308,100*
New 230kV Wind Connection Lines					
Radial 230kV Feeders	km	71	$35,500,000	149	$74,500,000
	Subtotal		*$35,500,000*		*$74,500,000*
Network Upgrades					
Resag line S53G	km	51	$4,442,302		$0
Replace wavetrap at Stanley		1	$108,243		$0
	Subtotal		*$4,550,545*		*$0*
	Total		**$62,781,620**		**$104,808,100**

Table 13-4. Cost Estimate – 900MW Scenarios, Transmission Plan 2.

New Facilities & Network Upgrades		*900 MW Transmission Plan 2*			
		Pembina Escarpment		*Diversified Development*	
New Network Transmission					
Wind Collector - St. Leon	km	25	$12,500,000	25	$12,500,000
Wind Collector - Stanley	km	40	$20,000,000	40	$20,000,000
	Subtotal		*$32,500,000*		*$32,500,000*
New Network Stations/Breakers					
Expand Stanley station	breakers	6	$22,731,075	4	$15,154,050
New 230kV Wind Collector station		4	$15,154,050	4	$15,154,050
Expand St. Leon station		1	$3,788,513	1	$3,788,513
Expand Glenboro station				1	$3,788,513
Expand Neepawa station				1	$3,788,513
	Subtotal		*$41,673,638*		*$41,673,638*
New 230kV Wind Connection Lines					
Radial 230kV Feeders	km	88	$44,000,000	157	$78,500,000
	Subtotal		*$44,000,000*		*$78,500,000*
Network Upgrades					
Resag line S53G	km	51	$832,932		$0
Replace wavetrap at Stanley		1	$108,243		$0
	Subtotal		*$941,175*		*$0*
	Total		**$119,114,813**		**$152,673,638**

© TransGrid Solutions Inc, 2010

For Transmission Plan 1, the cost estimate for the Pembina Escarpment plan is $62.78 million and for the Diversified Development plan is $104.81 million.

For Transmission Plan 2, the cost estimate for the Pembina Escarpment plan is $119.11 million and for the Diversified Development plan is $152.67 million.

900 MW Transmission Plan 1 is cheaper than 900 MW Transmission Plan 2 due to the fact that there is no new network transmission in 900 MW Transmission Plan 1.

For both transmission plans, the Diversified Development plan costs more than the Pembina Escarpment plan mainly due to the additional 230kV direct connect transmission lines, in particular the long direct connect lines from the Killarney and Minnedosa wind farms to Glenboro and Neepawa, respectively, in the Diversified Development plan.

The cost estimates for the 1200 MW Pembina Escarpment and Diversified Development wind generation scenarios for 230kV Transmission Plans 1 and 2 as well as the 500kV Radial Transmission Plan are provided in Tables 13-5, 13-6 and 13-7, respectively.

Table 13-5. Cost Estimate – 1200MW Scenarios, Transmission Plan 1.

New Facilities & Network Upgrades		***1200 MW Transmission Plan 1***			
		Pembina Escarpment		***Diversified Development***	
New Network Transmission					
Wind Collector - St. Leon	km	25	$12,500,000	25	$12,500,000
Wind Collector - Stanley	km	40	$20,000,000	40	$20,000,000
	Subtotal		*$32,500,000*		*$32,500,000*
New Network Stations/Breakers					
Expand Stanley station	breakers	6	$22,731,075	6	$22,731,075
New 230kV Wind Collector station		6	$22,731,075	5	$18,942,563
Expand St. Leon station		1	$3,788,513	1	$3,788,513
Expand Glenboro station				1	$3,788,513
Expand Neepawa station				1	$3,788,513
	Subtotal		*$49,250,663*		*$53,039,176*
New 230kV Wind Connection Lines					
Radial 230kV Feeders	km	134	$67,000,000	208	$104,000,000
	Subtotal		*$67,000,000*		*$104,000,000*
Network Upgrades					
Resag line S53G	km			51	$832,932
Reconductor line S53G	km	51	$4,442,302		
Reconductor line S60L Stanely-Letellier	km	63	$5,455,458		
Replace wavetrap at Stanley		1	$108,243	1	$108,243
Replace wavetrap at Letellier		1	$108,243		
	Subtotal		*$10,114,246*		*$941,175*
	Total		**$158,864,909**		**$190,480,351**

© TransGrid Solutions Inc, 2010

Table 13-6. Cost Estimate – 1200MW Scenarios, Transmission Plan 2.

New Facilities & Network Upgrades		***1200 MW Transmission Plan 2***			
		Pembina Escarpment		***Diversified Development***	
New Network Transmission					
Wind Collector - St. Leon	km	25	$12,500,000	25	$12,500,000
Wind Collector - Stanley	km	40	$80,400	40	$80,400
Wind Collector - Portage	km	70	$35,000,000	70	$35,000,000
Stanley - Letellier	km	65	$32,500,000	65	$32,500,000
	Subtotal		*$80,080,400*		*$80,080,400*
New Network Stations/Breakers					
Expand Stanley station	breakers	7	$26,519,588	7	$26,519,588
New 230kV Wind Collector station		7	$26,519,588	6	$22,731,075
Expand St. Leon station		1	$3,788,513	1	$3,788,513
Expand Letellier station		1	$3,788,513	1	$3,788,513
Expand Glenboro station				1	$3,788,513
Expand Neepawa station				1	$3,788,513
	Subtotal		*$60,616,201*		*$64,404,714*
New 230kV Wind Connection Lines					
Radial 230kV Feeders	km	134	$67,000,000	208	$104,000,000
	Subtotal		*$67,000,000*		*$104,000,000*
Network Upgrades					
Resag line S53G				51	$828,061
Reconductor line S53G		51	$4,442,302		
Replace wavetrap at Stanley		1	$108,243		
	Subtotal		*$4,550,545*		*$828,061*
	Total		**$212,247,146**		**$249,313,174**

© TransGrid Solutions Inc, 2010

Table 13-7. Cost Estimate – 1200MW Scenario, 500kV Radial Transmission Plan.

New Facilities & Network Upgrades		***Radial 500kV Transmission Plan***	
		Pembina Escarpment	
New Network Transmission			
Wind Collector - Dorsey 500kV	km	128	$160,000,000
	Subtotal		*$160,000,000*
New Network Stations/Breakers			
Expand Dorsey 500kV station	breakers	1	$6,494,593
New 230kV Wind Collector station		7	$26,519,588
New 500-230kV transformer breakers		2	$12,989,186
New 500-230kV transformers	transformer	2	$77,935,116
	Subtotal		*$123,938,482*
New 230kV Wind Connection Lines			
Radial 230kV Feeders	km	148	$74,000,000
	Subtotal		*$74,000,000*
Network Upgrades			
none			$0
	Subtotal		*$0*
	Total		**$357,938,482**

For 1200 MW Transmission Plan 1, the cost estimate for the Pembina Escarpment plan is $158.86 million and for the Diversified Development plan is $190.48 million.

For 1200 MW Transmission Plan 2, the cost estimate for the Pembina Escarpment plan is $212.25 million and for the Diversified Development plan is $249.31 million.

1200 MW Transmission Plan 1 is cheaper than 1200 MW Transmission Plan 2 due to the fact that there is less new network transmission in Transmission Plan 1.

For both transmission plans, the Diversified Development plan costs more than the Pembina Escarpment plan mainly due to the additional 230kV wind connection transmission lines, in particular the long direct connect lines from the Killarney and Minnedosa wind farms to Glenboro and Neepawa, respectively, in the Diversified Development plan.

The 500kV radial transmission plan costs more than any of the 230 kV transmission plans, at a total of $357.94 million. The major reasoning is due to the higher cost of 500kV transmission compared to 230kV, as well as the two 230-500kV transformers that are required.

The No Wind scenario, in which future load is supplied by thermal units at Selkirk and Brandon, requires no new network transmission or network upgrades.

13.3. Value of Loss Savings

The analysis in Section 8 determined that all of the wind generation scenarios result in a reduction of system losses[3] compared to the base case, due to the fact that the wind generation is closer to the Manitoba load center than the northern hydro generation that is being displaced in this study. The same is true for the No Wind scenario discussed in Section 12.

[3] These losses do not include the losses in the wind plants and collector systems below the 230kV level.

© TransGrid Solutions Inc, 2010

Using the following formula,

Annual energy cost = Peak loss savings (MW)*Capacity factor*8760 hours*Energy value ($/MWh)

the net present values (NPV) of the net loss savings were calculated for the wind generation scenarios and the No Wind scenario over a period of 30 years at interest rates of 6.0% and 8.5%, at energy values of $50/MWh and $70/MWh. Typical capacity factors for the wind plants could be assumed to be between 30% and 40%, therefore an average value of 35% was used.

The reduction in losses were averaged for each season for the cases using one and two 500kV MH-US tie lines as shown in Table 13-8.

Table 13-8. Average Reduction in Losses per Season.

Transmission Plan	*Average Loss Reduction (MW)*					
	Pembina Escarpment			*Diversified Development*		
	Summer Off-Peak	*Summer Peak*	*Winter Peak*	*Summer Off-Peak*	*Summer Peak*	*Winter Peak*
600 MW Wind						
Plan 1	71.0	85.5	89.0	78.0	95.0	101.0
900 MW Wind						
Plan 1	94.5	123.5	122.0	107.5	132.5	117.5
Plan 2	101.5	123.5	131.0	105.0	130.0	141.0
1200 MW Wind						
Plan 1	113.5	142.0	152.0	125.5	156.5	170.0
Plan 2	118.5	149.0	158.5	128.5	161.0	174.0
500kV Radial Plan	103.0	120.0	121.5	-	-	-
No Wind						
None	105.5	135.5	144.5	-	-	-

In order to calculate the 30-year NPV of the loss savings, it was assumed that these average loss savings are split equally throughout the year, i.e. that 33% of the time summer off-peak load applies, 33% of the time summer peak load applies and 33% of the time winter peak load applies.

The 30-year NPV of the net loss savings for the wind generation scenarios and the No Wind scenario compared to the base case northern hydro generation scenario are summarized in Table 13-9.

Table 13-9. 30-year NPV of net loss savings with wind generation.

Transmission Plan	*30-Year NPV Net Loss Savings ($ millions)*							
	Pembina Escarpment				*Diversified Development*			
	$50/MWh		*$70/MWh*		*$50/MWh*		*$70/MWh*	
	8.5%	*6.0%*	*8.5%*	*6.0%*	*8.5%*	*6.0%*	*8.5%*	*6.0%*
600 MW Wind								
Plan 1	133.5	171.0	186.9	239.3	149.0	190.8	208.6	267.1
900 MW Wind								
Plan 1	184.8	236.8	258.8	331.5	194.4	248.9	272.1	348.5
Plan 2	193.5	247.9	271.0	347.1	204.4	261.8	286.2	366.6
1200 MW Wind								
Option 4	221.5	238.8	310.2	397.3	245.7	314.7	344.0	440.6
Option 7a	231.6	296.6	324.2	415.3	252.0	322.8	352.8	451.9
500kV Radial Option	187.3	239.9	262.2	335.8	-	-	-	-
No Wind								
None	209.6	268.4	293.4	375.8	-	-	-	-

© TransGrid Solutions Inc, 2010

13.4. Summary

Table 13-10 summarizes the cost estimates for the No Wind scenario the wind scenarios. It also provides the range of the NPV of potential loss savings of a 30-year period associated with each plan.

Table 13-10. Cost estimates for Transmission Plans and Value of Loss Savings.

Transmission Plan	*Cost Estimates ($ millions)*					*Range of Loss Savings ($ millions)*	
	New Network Transmission	*New Stations/ Breakers*	*New 230kV Wind Lines*	*Network Upgrades*	*Total*	*Min*	*Max*
600 MW – Pembina Escarpment							
Plan 1	0.00	18.94	10.00	0.83	29.78	133.5	239.3
600 MW – Diversified Development							
Plan 1	0.00	22.73	60.00	0.00	82.73	149.0	267.1
900 MW – Pembina Escarpment							
Plan 1	0.00	22.73	35.50	4.55	62.78	184.8	331.5
Plan 2	32.50	41.67	44.00	0.94	119.11	193.5	347.1
900 MW – Diversified Development							
Plan 1	0.00	30.31	74.50	0.00	104.81	194.4	348.5
Plan 2	32.50	41.67	78.50	0.00	152.67	204.4	366.6
1200 MW – Pembina Escarpment							
Plan 1	32.50	49.25	67.00	10.11	158.86	221.5	397.3
Plan 2	80.08	60.62	67.00	4.55	212.25	231.6	415.3
1200 MW - Diversified Development							
Plan 1	32.50	53.04	104.00	0.94	190.48	245.7	440.6
Plan 2	80.08	64.40	104.00	0.83	249.31	252.0	541.9
1200 MW – Pembina Escarpment							
500kV Radial	160.00	123.94	74.00	0.00	357.94	187.3	335.8
No Wind							
None	0.00	0.00	0.00	0.00	0.00	209.6	375.8

© TransGrid Solutions Inc, 2010

14. Conclusions

14.1. Wind Scenarios

Of the transmission plans that were studied in detail, there was not a significant difference observed in the dynamic performance of the system when comparing the various plans; the dynamic performance was found to be acceptable for the power flow cases that were investigated. In addition, the SCR at all wind POIs was greater than 3, and the short circuit impacts to the system were minimal. Therefore, the comparison of transmission plans comes down more to cost, impact to system losses and MH-US loop flow, and a plan that could be logically staged.

All wind scenarios were found to reduce the system losses and MH-US loop flow compared to the base case.

14.1.1. 500kV vs. 230kV Transmission

Even at the 1200 MW wind generation level, 500kV transmission was not more efficient than 230kV transmission. The 230kV transmission plans have the following benefits when compared to the 500kV transmission plan:

- Lower cost
- Higher value of loss savings over 30 years

There are several additional drawbacks to the 500kV transmission plan.

1) It is less reliable than the meshed 230kV plans. If the 500kV wind-Dorsey line trips, all of the wind generation is lost.

2) There is a risk of subsynchronous control interactions if a Type 3[4] wind turbine is connected radially to a series compensated line. Depending on where the 500 kV wind line would be terminated into the 500kV Dorsey ring bus, it may be next to a series-compensated line, in which case a single contingency could cause the 500kV wind line to be connected radially to the 500kV series-compensated line. If it were more breaker positions away, then it would take more contingencies to cause this situation. The number of contingencies would dictate the risk involved and would determine what type of mitigation to pursue.

3) Another potentially bad situation that could occur is if the 500kV wind line ever tripped at the same time as the 500kV Dorsey-Forbes line when operating a maximum MH-US export. This could potentially result in the loss of ~900 MW of wind power plus the DC reduction due to loss of the 500kV line, for a total power loss of around 2500 MW, which would exceed the contingency reserves in the MISO pool and would be a reliability concern and a likely show stopper. This would be a NERC Category C event as it would take at least one prior outage to get to this

For these reasons, the 500kV radial transmission plan is not recommended.

14.1.2. Pembina Escarpment vs. Diversified Development

For the wind development scenarios, when comparing the Pembina Escarpment plan to the Diversified Development plan, the following conclusions can be made regarding the Diversified Development plan:

Pros:

- Fewer network upgrades are required for the same transmission plan
- More savings in system losses over 30 years

[4] This is not an issue for Type 4 wind turbines.

© TransGrid Solutions Inc, 2010

- Less MH-US loop flow

Cons:

- Higher total length of 230kV direct connect transmission lines
- Higher cost estimate (not considering saving in losses)

14.1.3. Staging of the Transmission Plans with Increased Wind Generation

The transmission plans investigated in this study could be staged as more wind farms are added.

Figure 14-1 shows an example of how the Pembina Escarpment plan could evolve from 600 MW to 900 MW to 1200 MW. The network upgrades for each stage are not shown but would be required. A similar staging plan could apply to the Diversified Development plan.

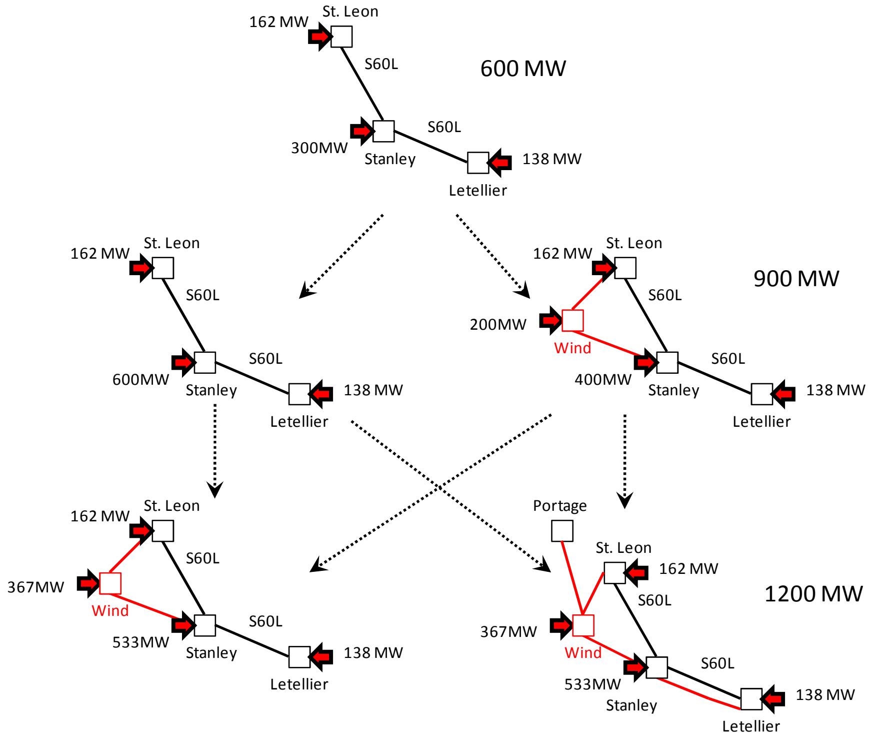


Figure 14-1. Example of staged plan to interconnect 600 MW, 900 MW and 1200 MW of wind.

14.1.4. Impact of a 2nd 500kV MH-US Tie Line

The same transmission plans were studied for the cases with one and two 500kV MH-US tie lines. The results of the steady state contingency analysis showed lower network overloads with the second 500kV tie line in service. Despite the fact that the overloads were lower, the overloads were still present and ended up requiring the same mitigation to fix the overloads as the cases with only one 500kV tie line. One exception is the 600 MW Transmission Plan 1, the second 500kV tie line negates the need for resagging line S53G for the Pembina Escarpment plan. Otherwise, all network upgrade requirements were the same whether there were one or two 500kV tie lines. In addition, the total interconnection costs were governed more by the new facilities needed to connect the wind generation, including the direct connect and new 230kV network facilities rather than the cost of network upgrades. Therefore the second 500kV tie line had no significant impact on the total cost of interconnection.

In terms of impacts to system losses, the reduction in losses observed with the wind generation scenarios was similar whether one or two 500kV lines were in service, usually the results were within 10 MW.

© TransGrid Solutions Inc, 2010

In terms of impacts to MH-US tie line power flows, a slightly bigger increase on L20D south flow was observed if the second 500kV tie line was in service. With two 500kV tie lines, L20D south flow increased in the range of 65-90 MW with the wind generation scenarios, as opposed to 52-80 MW with only one 500kV tie line. However, the steady state south flow on L20D was around 60-130 MW lower in the case with the second 500kV tie line, therefore the slightly larger increase in L20D south flow observed with the wind generation if the second 500kV tie line is present is not necessarily an issue. Further analysis at more stressed NDEX conditions would be required to determine if the increase in south flow on L20D would require L20D upgrades.

14.2. No Wind Scenario

Supplying future load via thermal units at Brandon and Selkirk, as well as via hydro generation at Conawapa, was not found to require any new transmission or network upgrades.

With the retirement of Brandon unit 5 (105.9 MW) in 2018, the analysis found that an additional 88.6 MW would be needed at Brandon to maintain the same MHEX levels and serve the same Manitoba load levels as the base cases. This is in addition to the two 140 MW units at Brandon and the two 70 MW units at Selkirk. Although no new transmission or network upgrades are needed, there would be some termination costs associated with this new thermal generation. These termination costs are not considered in this report.

Like the wind scenarios, the no wind scenario reduced system losses as well as MH-US loop flow, but to a lesser degree than the wind scenarios.

The no wind scenario increased the short circuit levels at various southern Manitoba 230kV and 110kV buses, significantly more so than the wind scenarios. Further investigation into the increased fault levels would be required to determine if the levels are acceptable, however it can be stated that all impacted fault levels remained below 40kA, with the exception of the Dorsey 230kV bus which in the worst case increased from 57.8 kA to 61.2 kA.

© TransGrid Solutions Inc, 2010

15. References

[1] Manitoba Hydro, "Interconnection Facilities Study Report, Resource Solicitation Process, St. Joseph 300 MW Wind Farm", December 2009, http://oasis.midwestiso.org/documents/Mheb/St_Joseph_IFS-final-Dec_18-stmp.pdf.

[2] GE Energy, "Modeling of GE Wind Turbine-Generators for Grid Studes", K. Clark, N. Miller, J. Sanchea-Gasca, Verson 4.3, April 8, 2009.

[3] Siemens PTI, "PSS®E Wind Modeling Package for GE 1.5/3.6/2.5 MW Wind Turbines, User Guide", Y. Kazachkov, P. Keung, K. Patil, Issue 5.1.0, June 2009.

[4] Manitoba Hydro, "Transmission System Interconnection Requirements", April 2009. http://oasis.midwestiso.org/oasis/MHEB

[5] Manitoba Hydro, "Erikson Wind Farm Interconnection Facilities Study", December 2009, http://oasis.midwestiso.org/documents/Mheb/Erikson%20IFS%20Report%20Final%20Dec%2018%2009.pdf.

[6] G904 document

[7] Manitoba Hydro, "Lena Wind Farm Interconnection Facilities Study", May 2006, http://oasis.midwestiso.org/documents/Mheb/ifs-lena-report.pdf

[8] A.K. Jindal, G.D. Irwin, D.A. Woodford, "Sub-Synchronous Interactions with Wind Farms Connected Near Series Compensated AC Lines", 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant, Quebec, Canada, October 2010.

[9] K. Clark, N.W. Miller, J.J. Sanchez-Gasca, "Modelling of GE Wind Turbine-Generators for Grid Studies", version 4.4, Sept. 2009.

[10] D.A.N. Jacobson, J. Laninga and R. Brandt, "Wind Interconnection in Manitoba", *2006 Cigre Canada Conference on Power Systems*, Montreal.

[11] NERC Special Report, *Accommodation of High Levels of Variable Generation*, April 2009. www.nerc.com

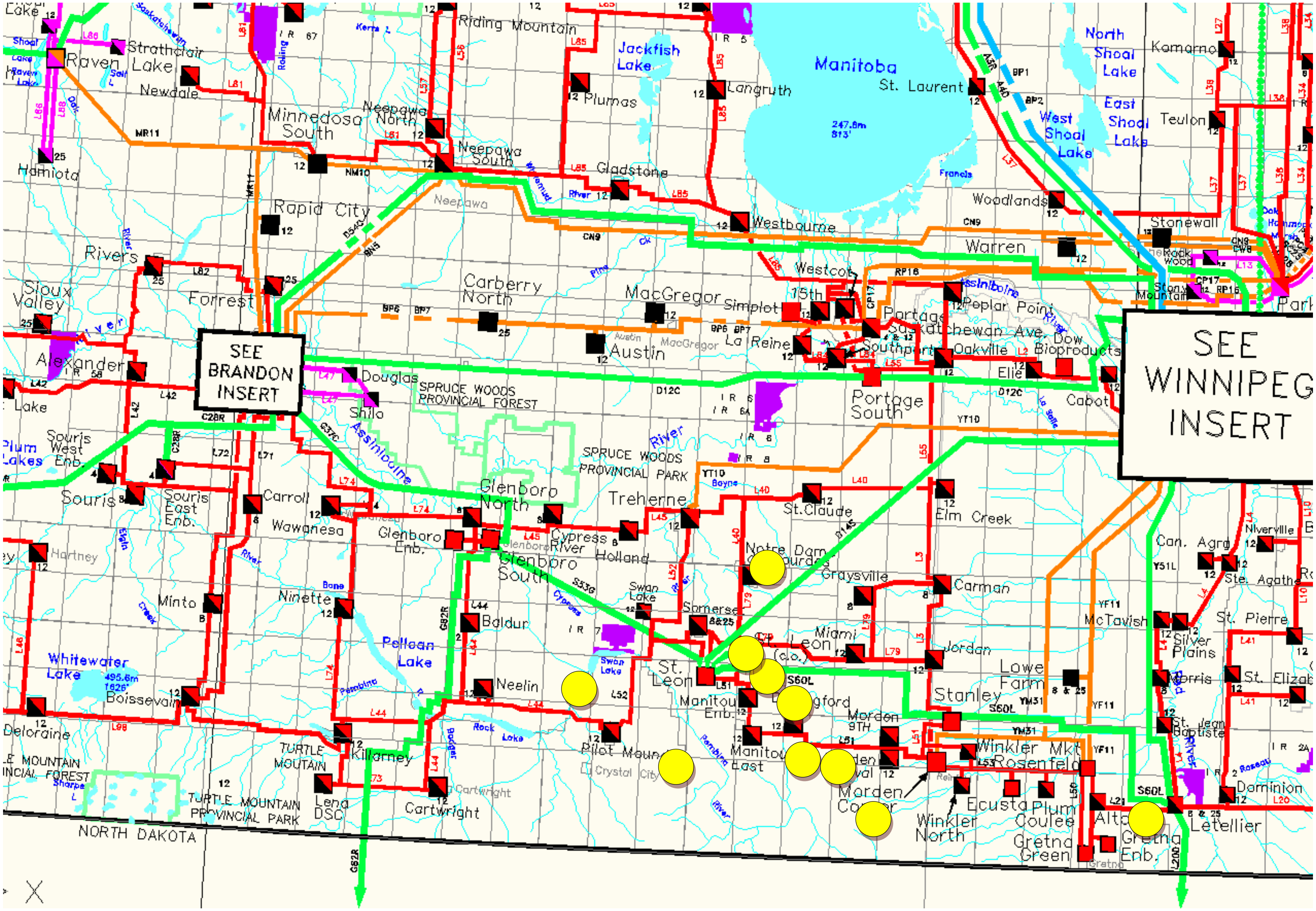
[12] D.A.N. Jacobson, R. Ostash, B. Bagen, P. Wang, S. Shelemy, "Large Scale Wind Interconnection Studies at Manitoba Hydro", 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant, Quebec, Canada, October 2010.

© TransGrid Solutions Inc, 2010

Appendix 1 – Geographic Locations of Wind Farms

© TransGrid Solutions Inc, 2010

Approximate Geographic Locations of Pembina Escarpment Wind Farms



Approximate Geographic Locations of Diversified Development Wind Farms